AALTO UNIVERSITY
SCHOOL OF SCIENCE
Degree Program in Industrial Engineering and Management

Juho Hoikka

Managing the Energy Performance of a Large Building Stock

Master's Thesis

Espoo, September 23, 2014

Supervisor: Professor Jan Holmström

Instructors: Tuomo Vähätiitto, M.Sc. (Tech.), M.Sc. (Econ.)
Raimo Tero, M.Sc. (Tech.)

AALTO UNIVERSITY SCHOOL OF SCIENCE
Degree Program in Industrial Engineering and Management

ABSTRACT OF THE MASTER´S THESIS

Author: Juho Hoikka		
Subject of the thesis: Managing the Energy Performance of a Large Building Stock		
Number of pages: 73	Date: Sep 23, 2014	Library location: TU
Professorship: Industrial Management		Code of professorship: TU-22
Supervisor: Professor Jan Holmström		
Instructors: Tuomo Vähätiitto, M.Sc. (Tech.), M.Sc. (Econ.) and Raimo Tero, M.Sc. (Tech.)		

Up to a quarter of all energy used in Europe is consumed in residential buildings. This is a significant share not only environmentally but also economically. Thus, it is increasingly important to focus on cutting energy consumption. Energy performance management is an essential task especially for property management companies since rising energy prices create significant cost pressures for many of them.

It is possible to reduce energy consumption and costs by investing in energy efficiency of the buildings. However, improvements need to be made in a structured and coordinated manner in order to achieve full benefits from the investments. A missing process to implement the energy conservation measures may lead to lost economic and environmental benefits.

This thesis presents a new process called Energy Operations Management (EOM) as a solution to this problem. It is a continuous process to manage the energy performance and conservation measures in a building stock. Key functions of the process include analyzing the energy consumption of the building stock and identifying the residential buildings that lack energy efficient systems. Based on the analyses, special attention will be given to inefficient buildings in order to improve the energy performance.

EOM was tested with a sample of energy consumption data and it proved to be a functional system to manage the energy performance in a large building stock. However, further tests within a longer period of time are required to verify the functionality of the EOM in various situations.

Keywords: residential buildings, building stock, energy management, energy performance	Publishing language: English

AALTO-YLIOPISTO DIPLOMITYÖN TIIVISTELMÄ

Perustieteiden korkeakoulu

Tuotantotalouden koulutusohjelma

Tekijä: Juho Hoikka		
Työn nimi: Energiatehokkuuden johtaminen suuressa rakennuskannassa		
Sivumäärä: 73	Päiväys: 23.9.2014	Työn sijainti: TU
Professuuri: Teollisuustalous		Koodi: TU-22
Työn valvoja: Professori Jan Holmström		
Työn ohjaajat: Tuomo Vähätiitto, DI, KTM ja Raimo Tero, DI		

Euroopan energiasta jopa neljäsosa kuluu asuinrakennuksissa. Se on hyvin merkittävä määrä niin ekologisesti kuin taloudellisestikin. Energiankulutuksen hallitseminen on erityisen tärkeää yrityksille, jotka omistavat suuren rakennuskannan. Suuri energiankulutus yhdistettynä eri energiamuotojen nouseviin hintoihin luo jatkuvasti kasvavia kustannuspaineita monille yrityksille.

Rakennusten energiankulutusta on kuitenkin mahdollista hallita ja pienentää investoimalla energiatehokkaisiin ratkaisuihin. Saadakseen investoinneista mahdollisimman suuren hyödyn irti, tulee ne toteuttaa suunnitellusti sekä järjestelmällisesti. Jos järjestelmällistä prosessia energiankulutuksen hallitsemiseen ei ole, on suuri riski, että osa saavutettavissa olevasta hyödystä jää saavuttamatta.

Tämä työ esittelee uuden rakennusten energiatehokkuuden johtamisprosessin nimeltä ”Energy Operations Management (EOM)” ratkaisuna energiatehokkuuden johtamiseen. EOM-prosessin keskeisimmät osat ovat kulutusdatan analysointi, tehottomien rakennusten tunnistaminen rakennuskannasta sekä huomion kohdistaminen rakennusten energiatehokkuuden parantamiseen.

EOM-prosessin toimivuutta testattiin energiankulutusdatalla, minkä perusteella prosessi osoittautui käytännölliseksi. Jotta saataisiin varmuus EOM:n toimivuudesta laajemmin, pitää sitä kuitenkin vielä testata monipuolisemmin pidemmällä aikavälillä.

Avainsanat: asuinrakennus, kiinteistökanta, energiatehokkuus, energiatehokkuuden johtaminen	Julkaisukieli: englanti

ACKNOWLEDGEMENTS

This thesis finalizes my studies that started in the former Helsinki University of Technology in Otaniemi already in 2007. Now that I am about to graduate after a series of wonderful experiences and important teachings from Aalto University, it is time to thank the people involved in the journey.

First of all, I would like to thank the people at TA-Yhtiöt for giving me the opportunity to make this thesis a really hands-on study in a business context. I thank especially Tuomo Vähätiitto and Raimo Tero for making this possible and guiding the research work at TA. In addition, I thank my supervisor Professor Jan Holmström for all of the guidance related to this thesis.

During my studies, I was an active member of the Guild of Industrial Engineering and Management, Prodeko. Sometimes it felt like the activities I participated in and the people I got to know taught me much more than all of the classes I took. I am especially thankful for the people in Prodeko's boards of 2010 and 2011 as well as the teams in excursions to Brazil and Asia. In addition, I am grateful to be a part of the entrepreneurship scene (Aaltoes, Slush and AVP) in Aalto during later years of my studies. I learnt a lot and met a bunch of amazing people!

I am also highly thankful to my mom, dad, and sister who have successfully supported and guided me throughout the whole 18 years I spent in different schools. Finally, I thank my dear Emma for being there for me.

Juho Hoikka
Espoo, September 23, 2014

ABBREVIATIONS

BAT	Best Available Technology
BAS	Building Automation System
BEMS	Building Energy Management System
CCE	Cost of Conserved Energy
COP	Coefficient of Performance
CUSUM	Cumulative Sum of Differences
DD	Degree Day
DHW	Domestic Hot Water
ECM	Energy Conservation Measure
EEI	Economic Energy Intensity
EIS	Energy Information System
EIU	Energy Intensity of Usage
EOM	Energy Operations Management
EPM	Energy Performance Model
EPI	Energy Performance Index
HDD	Heating Degree Day
HVAC	Heating, Ventilation, and Air Conditioning
M&V	Measurement and Verification
PDCA	Plan – Do – Check – Act, a continual improvement framework
RB	Reference Building
SEC	Specific Energy Consumption

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

According to studies, buildings use up to 40 % of the final energy consumption in the European Union, and 63 % of this consumption happens in residential buildings (Poel, van Cruchten et al. 2007). It is a significant share not only economically but also environmentally. Therefore, the building sector is a very promising place to improve energy efficiency performance since the potential for developments is high. Especially, refurbishing existing buildings offers an excellent opportunity to improve the performance of the building stock.

The energy consumption of buildings is a widely researched topic in academia. Literature introduces many different methods for energy consumption measurement and benchmarking not only for single office and apartment buildings but also for larger building stocks. In addition, examples of best practices can be found for energy consumption reduction from the studies made around the world. The importance of energy saving is highlighted within organizations that own a large number of properties. In a large building stock even modest proportional savings in energy consumption will result in measurable financial savings (Nousiainen 2006).

Approximately 40 % of European buildings are constructed prior to 1960s making them over 50 years old (Economidou 2011). At that time, the energy regulations were very limited compared to the situation at the moment. That is one of the reasons why it has been identified that the most feasible way to reduce consumption is by acting on the existing building stock (Dall'O', Galante et al. 2012).

1.1 Background

Over recent years, companies as well as consumers have become more and more aware of the importance and benefits of saving energy. Improving energy efficiency in buildings has even reached the national news multiple times in Finland. Due to increasing energy prices and cold weather conditions even single households are able to achieve measurable energy cost savings by implementing energy conservation measures. However, this issue is highlighted within organizations that own numerous properties. These companies face cost pressures from the increasing energy prices due to the multiplier impact caused by the large building stock. Fortunately, energy consumption and costs can be managed.

The energy consumption tends to increase when the building stock expands and grows older because the condition of building elements and systems deteriorate in time. To fight deterioration, refurbishments need to be performed constantly. Due to the high complexity and multiple possibilities for refurbishments, a systematic and continuous process is needed to manage the energy performance of a building stock. Otherwise, the largest benefits may not be reached, and refurbishments and energy efficiency investments may become just a set of interrelated actions.

Motivated by these challenges this thesis was written as an assignment for a company called TA-Yhtiöt. TA is a company owning multiple apartment properties and therefore facing the challenges of rising energy costs. TA is eager to tackle this problem and discover new opportunities to reduce energy costs and manage energy performance investments.

1.2 Objective

Golabi et al. (1982) described in their article from the 80's how they built a decision making tool and a systematic maintenance process for highway pavement management. The tool divided the network of highways into one mile long segments. Next, maintenance action suggestions were given by analyzing each segment based on different criteria regarding the condition of the highway. The segments had a minimum condition criteria and the whole system took into account also total budgetary restrictions. Earlier, roads were allowed to deteriorate to a poor state until an extensive maintenance operation was made. However, it was noticed that a much better way is to perform more frequent and minor preventive measures to stop roads from deteriorating into poor condition. Frequent minor actions are also less costly than larger corrective measures. By implementing the new management system they were able to change away from "a subjective nonquantitative method to modern system that integrates managerial policy decisions and engineering inputs through an optimization system". (Golabi, Kulkarni et al. 1982)

It is possible to utilize a similar method to Golabi's pavement management system to analyze the energy performance of large building portfolios. The method includes a set of measurements and analyses to determine present condition, improvement actions, and long term goals. The individual buildings not performing according to the preset energy consumption targets are identified from the large portfolio. Next, the most suitable corrective action for that building is determined and implemented. In addition, long term goals are important in helping to track that the building portfolio as a whole is developing towards desired direction.

The key objective of this thesis is to create a systematic process to manage the energy performance of a building stock by studying relevant literature. An important part of the process of managing energy performance is to analyze the building stock to find the most inefficient buildings. As in any portfolio management, the performance of the whole portfolio is improved by adjusting and developing the individual factors (buildings in this case). At the same time, limited resources need to be used in the places where they are most effective.

A simple method to compare and benchmark single buildings is needed as well. At the moment, comparing two buildings is not necessarily straightforward since locations and characteristics of buildings can vary widely between each other. As a result, it is not possible to make direct comparisons between, for example, total energy consumptions or total costs. What makes the issue even more complicated is that the buildings with the highest specific energy consumption (SEC) may not be the ones with the best improvement potential from the economical point of view because energy prices vary widely across different regions in Finland. Therefore, it is also important to consider the total energy consumption and the total cost of the buildings to find the individuals with a high financial impact.

To guide the study process, research questions were formed. The central question of this thesis is how the energy performance of a building stock can be managed. This includes an issue whether a simple process to systemically improve the condition of the building stock can be identified. It is also important to describe what this process is like. The second central question is how to utilize the energy performance data in a most useful way to support the management process. Closely related to this issue is the question how to monitor the buildings to collect the performance data in the first place.

To sum up the essential parts of the research setup, a table was compiled to introduce them in a clear way. Thesis fundamentals are presented in the Table 1 below.

Table 1. Thesis fundamentals

Motivation	A systematic approach to manage energy efficiency improvements in a building stock is needed due to rising energy costs and slowly deteriorating condition of the buildings.
Thesis objective	To create a comprehensive and systematic process to manage energy performance of a large building stock.
Approach	Researching literature to discover useful practices in managing energy performance in buildings. Compiling these practices into a single easily usable framework and applying this framework on the case company.
Thesis scope	The scope of this thesis are the methods that can be used to manage and improve the energy efficiency of residential buildings in Finland.
Research questions	1. How the energy performance of a building stock can be managed? 2. How the energy performance data can be utilized in a useful way?

1.3 Research methods

This sub-chapter introduces the methodologies used to study academic literature as well as the framework to analyze the data in the case section.

Webster et al. (2002) covered the topic of writing a literature review in their article. They recommend a structured approach to determine the most relevant literature in the given field of study. The approach is divided into three steps. The first step, is to search articles from the leading journals because most probably the best articles can be found in them. The second step is to review the citations of the articles found in the first step. Finally, articles that are citing the articles found in the first two steps are identified.

The best way to organize a literature review is to use concept-centric organizing framework. This framework identifies the most relevant concepts and organizes the review according to those. In other words, key articles' and authors' findings are synthesized according to the concepts. In order to make the transition from author-centric to concept-centric it is recommended to use a concept matrix. The concept matrix is compiled while reading the articles by identifying the concepts introduced in the different articles and writing them down in the matrix. The final step is to write the review and synthesize the literature by discussing each concept that was found. (Webster 2002)

The framework described by Webster is easily implementable and practical considering the objectives of this thesis. Thus, it is used in the background of the analysis work for the literature review section concerning the energy performance of buildings.

The framework that will be used in the empirical section of this thesis is as follows: literature is utilized to identify the most interesting methods for managing the energy performance and to analyze energy consumption data in a building stock. Their usability in this particular case is evaluated and the most practical methods will be selected by compiling them into a single framework or process. These methods are then used together with the case specific data in order to get novel information concerning the state of a building stock and the applicability of the selected analysis methods in the chosen case.

1.4 Structure of the study

The central parts of the study are the literature review, case description and analysis, as well as the discussion and recommendations.

The introduction chapter highlights the importance of the issue and creates a motivation for the study. In addition, the objective and the research questions are formulated and the research methods are introduced in the first chapter. The second chapter, which is the literature review, creates the theoretical foundation and an understanding about the topic by researching the academic literature and other studies from the field. A synthesis of the literature is presented in the end of the literature review chapter. The synthesis is a new process called Energy Operations Management which is derived from the different findings presented in the literature.

The empirical part of the thesis begins in the third chapter by describing the case and introducing the current situation of the case company. Next, in the following chapter, new knowledge is created by analyzing the building stock of the case company with the methods that were discovered useful based on the literature study. Finally, the fifth chapter discusses the findings of this study and gives recommendations concerning the future actions.

2 LITERATURE REVIEW

A literature review was performed to gain understanding of recent findings from the academia and other research related to energy efficiency in buildings. The aim was to determine what kind of methods have been used to manage and measure the energy performance of a building stock. In addition, it was studied what kind of energy consumption metrics have been used to evaluate the building stock or a single building.

The literature review chapter is divided into five sections. The methods and findings of different authors as well as research projects are presented in sections 2.1 – 2.4. The section 2.1 presents a high level strategic view to energy management and describes how the energy management initiatives should be implemented and organized. The section 2.2 illustrates the way energy consumption can be measured in a large building stock. In the section 2.3, some (mainly statistical) analysis methods are presented. These methods can be used to analyze and transform the collected energy consumption data into usable information. Next, in the section 2.4, economic evaluation methods for energy efficiency investments are briefly discussed. Finally, a synthesis of the literature, which is the Energy Operations Management process, is presented in the section 2.5.

2.1 Systematic energy performance management

This section introduces different methods and concepts that are used to manage energy performance systemically. The first sub-section takes a strategic approach to energy management. Energy management need to be made a strategic activity for the company by taking a holistic view of it and making both long and short term strategies for energy management. Also, a clear written energy policy needs to be generated. The second sub-section is about making the energy performance improvements a continuous process. A so-called Plan – Do – Check – Act framework is introduced to help that task. In the third sub-section, energy assessments are examined more. There are multiple ways to arrange an assessment depending on the level of information needed and this issue is discussed. The last three sub-sections examine matters related to daily maintenance, real-time management, and employee involvement. They are also important aspects to consider when implementing systematic energy performance management.

2.1.1 Strategic approach to energy management

Capehart, Turner et al. (2006) defines energy management as “the efficient and effective use of energy to maximize profits (minimize costs) and enhance competitive positions”. Other desirable sub-objectives included reducing greenhouse gas emissions, cultivating excellent communications related to energy matters, developing and maintaining effective energy consumption monitoring, reporting and management strategies, finding new ways to increase returns from energy investments as well as developing interest towards energy efficiency from all employees. Capehart, Turner et al. (2006) divided the energy management program into three different components. First is the building automation system (BAS) that controls HVAC systems of the building and collects energy consumption data. The second, energy information system (EIS) processes the data and turns it into useful information. The third part is the commitment from the management and staff to the energy management program. All three of these components are needed in order to successfully run the program.

Energy management is a permanent and continuous process in an organization that aims to optimize and reduce energy consumed in buildings (Zhivov, Pietiläinen et al. 2009). In practice, this frequently means reducing energy consumption by making changes in operation and maintenance practices as well as making energy efficiency investments. Energy management is based on the information gotten from energy assessments that create an understanding of the energy consumption of the building. The amount of information and details discovered in the assessments varies depending on the level under evaluation (Figure 1). On the building stock level, the information is more general whereas on the component level information is much more detailed. (Zhivov, Pietiläinen et al. 2009)

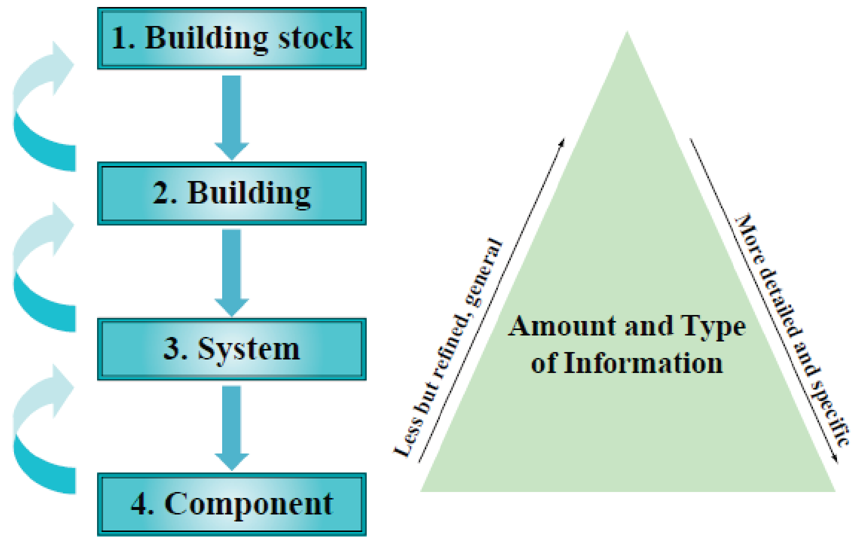

Figure 1. Levels of energy management and assessment (Zhivov, Pietiäinen et al. 2009)

Energy efficiency can be improved by having a systematic management process and by having both short and long-term strategies for energy efficiency management (Zhivov, Pietiläinen et al. 2009). Short-term strategy and activities focus on monitoring, benchmarking, and analyzing energy consumption in buildings as well as operating and managing buildings as efficiently as possible. This can be done by continuously measuring energy consumption, making minor improvements and setting monthly consumption targets. One of the most important tasks for short-term activities is to produce data for long-term planning. Long-term strategy, on the other hand, is focused on setting long-term performance targets and implementing refurbishments which improve the functional performance of the building. Both long-term and short-term aspects are summarized in Figure 2. In short, the goal of energy management as a whole is to reduce energy consumption while at the same time improve or maintain indoor conditions at pleasant level (Ihasalo 2012). One critical issue must be also remembered:

companies need to make profits in order to stay in operation. This means that all new operations need to increase revenues or cut costs to be sustainable in the long term. Managing energy consumption has proven to be cost effective multiple times (Capehart, Turner et al. 2006).

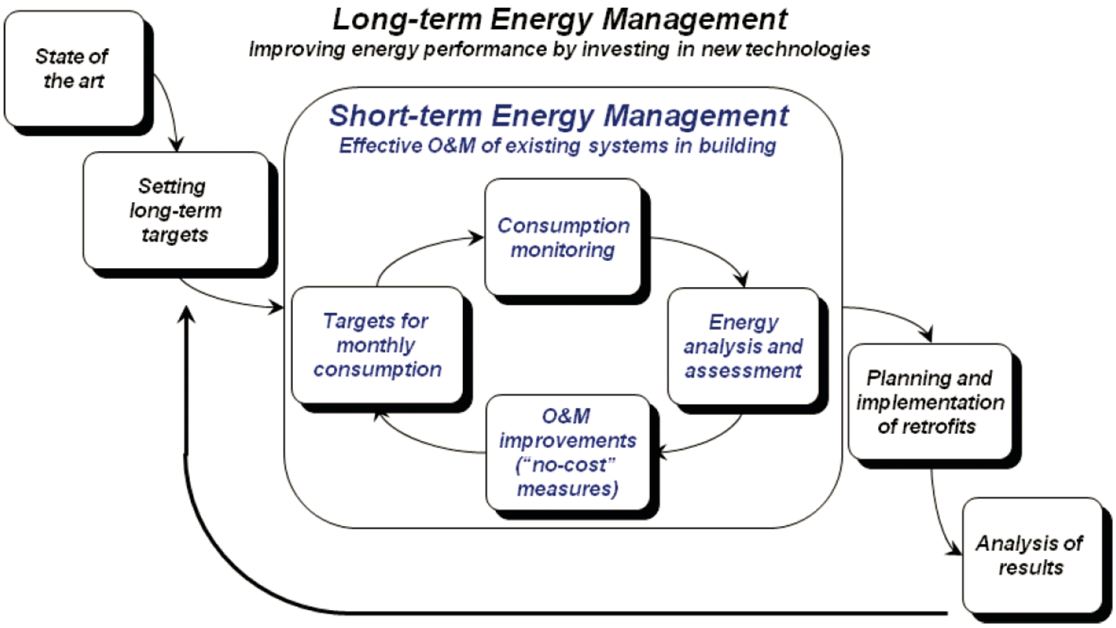

Figure 2. Long-term and short-term energy management (Zhivov, Pietiläinen et al. 2009)

The need for or a plan of an energy management program can come top-down from management to employees or it can come bottom-up from employees to management. Either the management recognizes a need to start improving energy usage or the employees identify the opportunity and start selling the concept to the management. Either way, one of the most important aspects in a systematic energy management program is that the top management is committed to the program. (Capehart, Turner et al. 2006)

Energy management program needs a single coordinator responsible for the program. This person should preferably report as high as possible in the whole organization. However, this may not be enough to run the program. The coordinator may need assistance from other employees and, in addition, two helping committees may be useful. Technical committee can help in complicated technical issues related to different energy solutions, and steering committee can guide activities and support in communication issues. (Capehart, Turner et al. 2006)

The energy management activities must be clearly connected to the strategy of the organization. Improvement actions may otherwise remain a series of uncoordinated one-time actions with no real changes or long-term impact. Also, changes in the organization (such as personnel or management) may affect negatively in the energy management operations if a company has not formalized its energy performance improvement actions in the form of an energy policy. Without a written policy other priorities may take the focus from controlling energy consumption. (Tripp 2005)

A formal written energy policy will be a public expression of the company's commitment to energy management. In addition, it will be a working document that provides continuity for employees. The policy can be divided into two parts. The first part is the expression of commitment towards energy management, and the second part is the practical operating policy. The first part can also be published for PR reasons. (Tripp 2005)

2.1.2 Improving energy performance continuously

Zhivov et al. (2009) states that "the final goal of energy management is to develop energy assessment as a process of continuous improvement rather than as a series of individual audit actions". Following the so-called PDCA circle will help to achieve the goal. The PDCA circle is a continuous process with four steps. First, in the process, a plan is created to improve performance. Next, the plan is implemented and performance is measured. Third step is to check whether the performance was as intended. Last step is to decide whether changes are needed to improve the process before it starts again from the beginning.

Capehart et al. (2006) suggested a measure – analyze – action cycle which follows the logic of PDCA circle. By measuring it is possible to collect data that can be analyzed. The data transforms into useful information only subsequent to analyzing it. This information is then used to implement energy efficiency improvement actions. These actions provide results and the circle starts from the beginning when the results are monitored. This circle is presented in Figure 3.

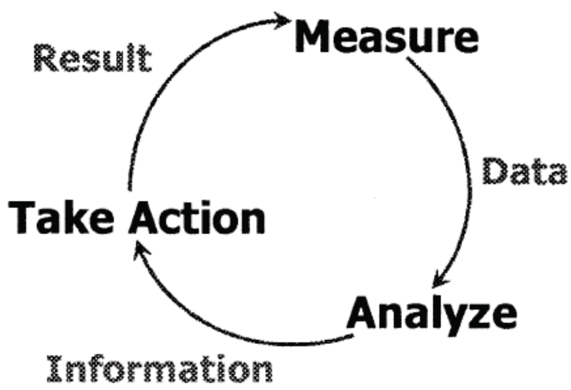

Figure 3. Measure - Analyze - Action cycle (Capehart, Turner et al. 2006)

EU is developing a new directive at the moment related to energy efficiency. It will have multiple requirements for companies but one of them is a requirement to perform energy audits to buildings on a regular basis (The Coalition for Energy Savings 2014). One of the ways for an organization to meet the requirements of the directive would be to implement an energy management system certified by ISO 50001.

The purpose of ISO 50001 is to *"enable organizations to establish the systems and processes necessary to improve energy performance, including energy efficiency, use and consumption"* (ISO 2011). The standard can be used by any organization regardless of size or location. By implementing the actions recommended by the standard, organizations are able to reduce their energy usage and costs. The ISO 50001 is also based on PDCA (Plan – Do – Check – Act) continual improvement framework and it *"incorporates energy management into everyday organizational practices"* (ISO 2011). The PDCA circle is presented in Figure 4.

"In the context of energy management, the PDCA approach can be outlined as follows:

- *Plan: conduct the energy review and establish the baseline, energy performance indicators (EnPIs), objectives, targets and action plans necessary to deliver results that will improve energy performance in accordance with the organization's energy policy;*
- *Do: implement the energy management action plans;*
- *Check: monitor and measure processes and the key characteristics of operations that determine energy performance against the energy policy and objectives, and report the results;*
- *Act: take actions to continually improve energy performance and the EnMS."* (ISO 2011)

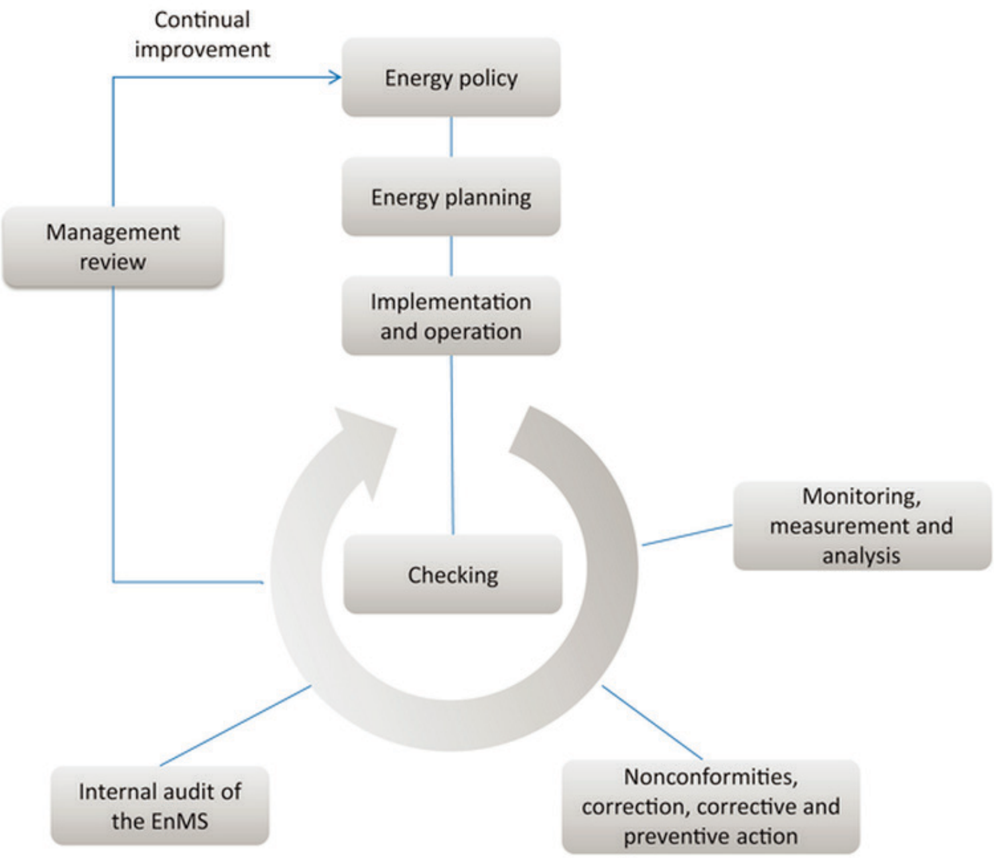

Figure 4. Energy management PDCA circle according to ISO 50001 (ISO 2011)

2.1.3 Implementing energy management and energy audits

Implementing energy management and assessment program can be divided into five steps (Zhivov, Pietiläinen et al. 2009). In the first step, energy management is planned and responsibilities are divided. This means that an energy assessment team should be appointed to run the activities. The team must familiarize themselves with energy consumption data and they have to start to follow project management practices to make sure that targets will be achieved. In the second step, monitoring of energy consumption is set up. Monitoring of energy usage is the basis of energy management. Monitoring energy consumption will show the usage patterns and reveal the buildings that use considerable amounts of energy. It is also important to ensure that basic data concerning the characteristics of buildings is easily available for further calculations. In addition, the second step includes comparing similar buildings with each other (i.e., benchmarking) which will highlight the buildings with greatest consumption. Next, the targets for level I-III assessments can be decided. In the third step the energy audits can be performed on chosen sites. Best way is to start with a walk-through audit prior to deciding on other methods on all sites. Another consideration is, whether audits will be done with own employees, or are external experts hired to perform the tasks. In the fourth step, a detailed action plan is developed to implement the energy efficiency measures. It allows prioritization and a systematic execution of the chosen actions. The action plan must be kept up to date by updating it at least annually. The goal is to use the action plan to make the improvements a continuous cycle that constantly works towards better energy performance. The final step is to keep all levels from the top management to the building user informed on the energy performance improvement actions and how the process is progressing. A summary of these five steps can be found in the Figure 5 below. (Zhivov, Pietiläinen et al. 2009)

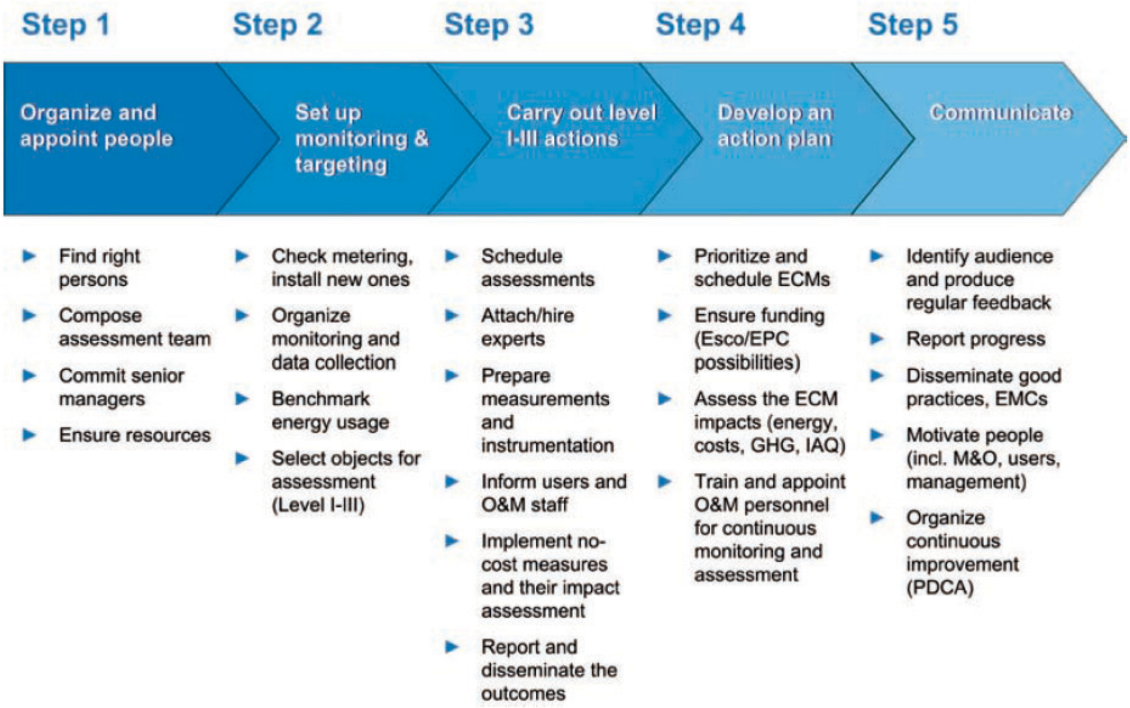

Figure 5. The five steps needed in the successful implementation of an energy management and assessment program (Zhivov, Pietiläinen et al. 2009)

Capehart, Turner et al. (2006), on the other hand, identified that performing an energy audit is the first task subsequent to the decision to start an energy management program. The energy audit is an analysis of current energy usage of a single building and it also identifies some preliminary methods of reducing energy consumption. An energy audit has four goals. First is to identify the types and costs of energy usage. The second is to gather understanding concerning energy usage. Third step is to identify new methods to reduce energy consumption. Finally, these new methods are analyzed from a financial point of view to discover their profitability.

Zhivov, Pietiläinen et al. (2009) uses the term energy assessment interchangeably with energy audit to depict the process of analyzing energy usage. According to them, an energy assessment is a systematic process the purpose of which is to evaluate existing energy consumption, identify the energy saving actions, and report findings. The assessment includes an analysis of energy streams in a single building or a building portfolio, evaluation of the target's saving potential, and recommendation of improvement actions. The energy assessment can be divided into six phases which are shown in Figure 6.

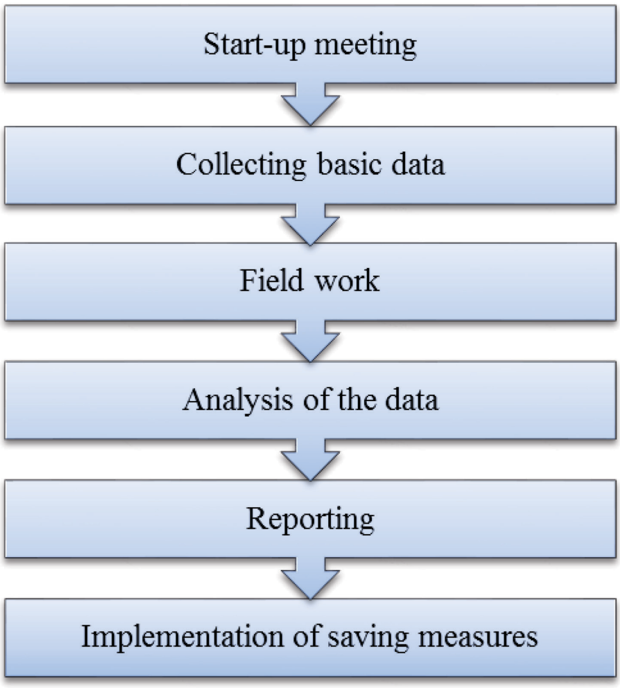

Figure 6. The six phases of energy assessment (Zhivov, Pietiläinen et al. 2009)

The energy audit can be done in different ways, depending on the resources and data availability as well as organization's commitment. The assessment can be divided into four levels depending on the depth of the assessment. The level 0 is the pre-assessment phase where data availability is checked and targets for audits are chosen. The first level is a quick walk-through audit where existing consumption figures are reviewed and benchmarked. Level 2 assessment has already detailed measurement of consumption, preferably on an hourly basis. The main goal is to get a deeper understanding of the energy consumption. The final level includes detailed engineering analysis as well as implementation, and it can require up to 1.5 years to accomplish. The third level also includes measuring and verifying the performance level that is achieved subsequent to the investments. This process is summarized in Figure 7. (Zhivov, Pietiläinen et al. 2009)

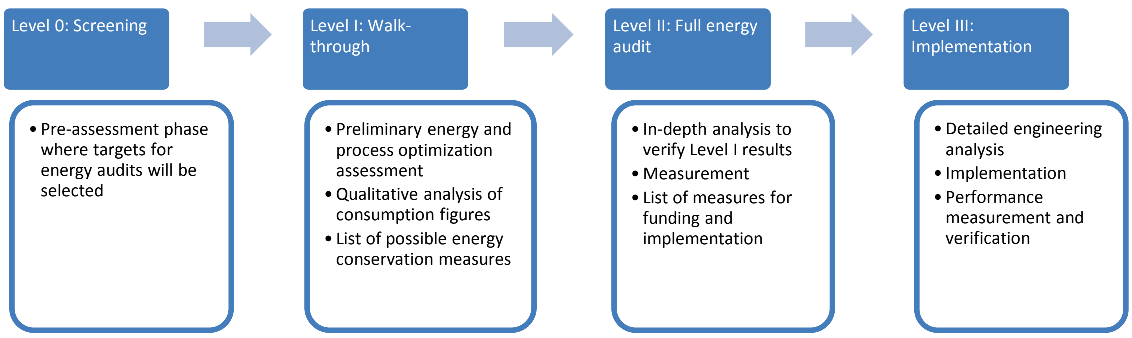

Figure 7. Different levels of energy assessments (Zhivov et al. 2009)

When energy assessments are performed deliberately on a regular basis, it will become a continuous scheme. Energy assessment scheme is defined by Zhivov, Pietiläinen et al. (2009) as a procedure where an owner of a large building stock analyzes various sites and buildings over a period of several years. To make the scheme purposeful, it is needed to set goals for it and there are two ways to do it. The first option is that the goal will be defined as a proportion of the building stock that should be assessed yearly. Another option is to make the goal as a target for energy consumption reduction. What is more, goals define the amount of resources needed in order to achieve them successfully.

It is recommended that the sites that will be assessed are planned 18 – 24 months in advance. This allows enough time for the budgeting to respond. The sites can be decided based on, for example, a rough analysis of specific energy consumption or high overall cost. It is also important to decide the target for each assessment site. When setting the targets, it must be remembered that a smaller amount of more detailed assessments can give a better result in energy savings compared to larger amount of walk-though assessments. The targets can be roughly divided into three categories: cream-skimming, comprehensive assessment, and first steps. Cream-skimming is a method to find the easiest savings. Comprehensive assessment, on the other hand, defines all possible savings for the given site while first steps method is used to identify areas for further assessments. Scope of the work can be limited to whole site, to only one type of a building, or to a single system. However, if too narrow scope is taken the findings may be limited and some inefficiencies out may be left out. It was also mentioned that in the Nordics energy assessments should be executed during the heating season because only then it is possible to discover the inefficiencies in the system. What is more, monitoring the energy assessment scheme is a very important task. It is essential to have data to prove than the scheme has been effective and to support its existence in the long-run. (Zhivov et al. 2009)

Due to the continuous improvement effort and assessments, a large amount of data and reports are created. However, energy assessment reports should be considered as continuously changing source for up-to-date information instead of a one-time study. In addition, energy assessment should be integrated into the daily operations and long-term planning of an organization in order to get the most out of it (Zhivov, Pietiläinen et al. 2009). Figure 8 shows how the results of energy assessment can be linked to continuous operation and long-term planning.

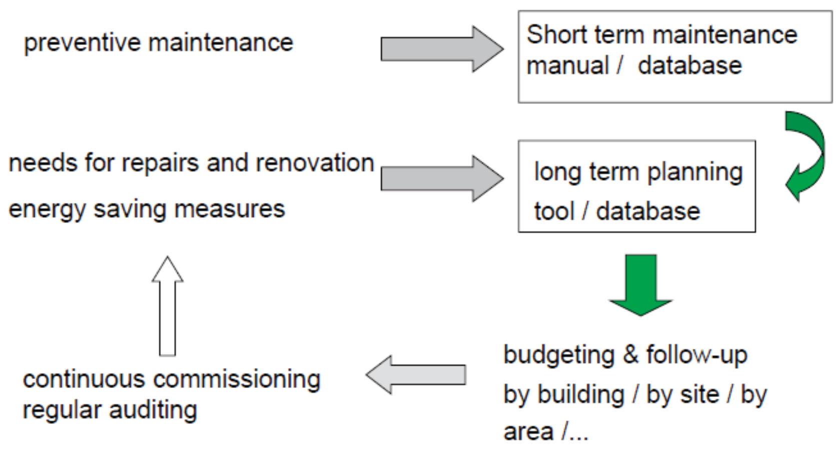

Figure 8. Linking energy assessment to continuous operation (Zhivov, Pietiläinen et al. 2009)

2.1.4 Daily building maintenance

Lewis (2011) performed case studies where they analyzed the link and interdependence between energy consumption and maintenance management. Frequently, these two issues are seen as independent challenges. However, maintenance and energy management are interdependent. Thus, it is important to take both into account if optimal performance is to be reached. Figure 9 illustrates this interdependency. The energy performance data of the building is required for optimal maintenance decisions, and proper maintenance is essential for acceptable energy performance. When the two are operated efficiently, it will reduce both maintenance and energy costs.

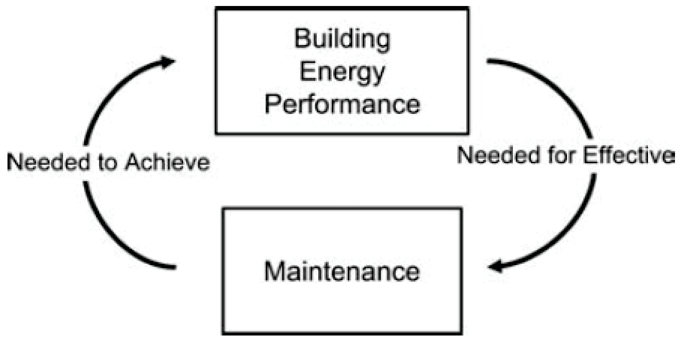

Figure 9. Link between building energy performance and maintenance

Lewis' (2011) case studies revealed that maintenance and energy management is frequently reactive. If energy consumption figures are read from energy bills, it is an example of reactive behavior and that will hinder the search of energy waste. "Fighting fires" with little or no time for planning is a typical symptom of reactive maintenance. Proactive maintenance and continuous building commissioning, on the other hand, would reduce total costs and the need for major retro-commissioning processes. However, it was noted that changing from reactive to proactive methods is a laborious and demanding task for an organization. (Lewis 2011)

2.1.5 Real-time remote energy management

Energy management can take a step even further when real-time data and remote control is used to monitor and operate buildings. Maattanen (2014) investigated how remote energy management service affected the energy consumption of two retail building portfolios. In the novel facility service concept, building processes were optimized nearly in real time with the remote management service. The buildings were monitored continuously from a central location, and the values were compared to predefined targets in a weekly cycle. This allowed reacting to deviations and implementing corrective measures on a short notice. Building processes were managed and optimized proactively and on-line depending on variables, such as temperature or CO_2 levels. The most frequent changes were done to the operating schedules of the building and resetting the set point values. The remote control center also collected suggestions for energy performance improvements on a regular basis. This kind of remote energy management service was able to achieve measurable savings in electrical and heat energy in the building portfolio. It was noticed that most benefits were gotten when the remote management was provided together with maintenance and technical services. It resulted in smoother information flow and because of freed resources the training of maintenance personnel was increased. (Maattanen 2014)

2.1.6 Employee involvement and training

Zhivov, Pietiläinen et al. (2009) highlights that people are an essential part in the energy management program in addition to technological solutions (Figure 10). Everyone in the organization must be involved in the process for it to be successful. Without the commitment of everyone, rewarding results will be difficult to achieve.

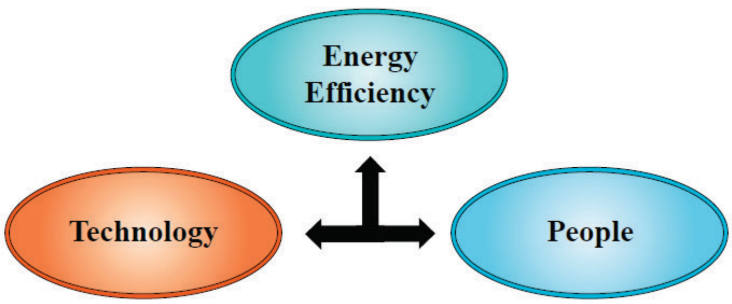

Figure 10. Both technology and people are important for energy efficiency (Zhivov et al. 2009)

It is very difficult for the energy management to meet its goals if all stakeholders from the top management to the daily maintenance personnel are not committed to improve energy performance. People need to know that their work is appreciated and that they really can make a difference. (Zhivov et al. 2009)

Informing and educating tenants on energy efficiency could be also beneficial. Tuominen et al. (2012) noticed in their study that the lack of information, promotion and education creates barriers for people to adopt energy efficient behavior. In addition, lack of skilled labor was identified in the study as one drawback in European countries. Thus, educating and hiring professionals to implement energy efficiency improvement is an important task for organizations. Also, The World Business Council for Sustainable Development (WBCSD 2009) identified skilled workforce as one of the important aspects when the energy efficiency is improved in the building industry.

2.1.7 A summary of systematic energy performance management

This section consisted of six key topics related to systematic energy performance management: strategic approach to energy management, continuous improvement, implementing assessments, daily maintenance, real-time management, and employee involvement. The key takeaways from this section are that a company needs to make the energy performance management a strategic issue and start to make improvements continuously in a well-structured manner. Important is also to notice the substantial effect of daily building maintenance to the energy performance of the building. In addition, it is very important to get all managers and employees of the company committed to the process of improving energy performance. In the future, when real-time data is available, it may open new possibilities to manage energy performance even more effectively.

2.2 Monitoring the energy performance of buildings

It has been noted that many times buildings do not perform as intended (Ihasalo 2012). Therefore, it is important to continuously measure the performance of a building. What is more, increasing amount of buildings have complex technology which makes the importance of performance assurance even greater (Ihasalo 2012). Proper energy consumption measurements, verification, and metrics are the basis for any kind of efficiency improvements because they help to create an understanding of the conditions of buildings. Without an understanding of the performance of a building it is not possible to determine the most efficient measures for improvement (Dall'O', Galante et al. 2012). Recently, the data collection has started to become more and more real-time. With proper analyzing tools and real-time energy consumption data it is possible to quickly see malfunctioning systems such as simultaneous heating and cooling in a building. In addition, measuring or performance tracking can help to identify problems prior to them turning into tenant complaints or equipment malfunction (Ihasalo 2012). It has been also identified that "a quick overview of the energy performance throughout the portfolio is critical for successful management" (Liu 2011).

This section introduces examples of systems that are used to monitor the energy performance and consumption of buildings. In addition, an array of different consumption metrics are suggested. Metrics are needed to gain a better understanding of the consumption and to be able to compare buildings. The final topic is energy consumption normalization. It is used to make the consumption figures of buildings located in different climatic regions comparable.

2.2.1 Systems for managing and monitoring performance

Bon identified already in 1994 that an effective real estate portfolio management needs a feedback loop between real portfolio performance and managerial action. This is achieved by monitoring the performance of the portfolio and using the help of statistical quality control to keep the chosen performance indicators between the desired control limits. The goal is to shift the average performance towards desired direction and reduce the variance around the average performance. This can be achieved by continuously performing improvement actions as well as adjusting and tightening the control limits. (Bon 1994)

It was noticed that the energy consumption of a building varies from year to year because of changes in factors, such as utilization rate, tenants, renovations and weather. This makes it difficult to measure energy consumption and compare the performance between different years. Especially, measuring electricity consumption was identified more laborious than measuring heat consumption because occasionally it is not possible to separate the consumption of the building from tenants' consumption. In order to reliably compare the consumptions of consecutive years it should be possible to separate the changes in energy consumption due to different reasons. Improved energy consumption measurement methods in buildings would help in this problem. (Nousiainen 2006)

Capehart, Turner et al. (2006) calls the IT and other management systems that gather energy consumption data for managerial use as Energy Information System (EIS). The definition for EIS is "equipment and computer programs that let users measure, monitor and quantify energy usage of their facilities and help identify energy conservation opportunities". It was also noted that the backbone if this kind of system is the continuous feedback on utility performance. EIS can be divided into two parts. The first part is energy consumption data collection, and the second part is publishing this data on web. It is important to remember that the collected data is useless unless it can be turned into easily interpretable and actionable information. The key is to present the metered data in the form of charts and graphs. Also, the more metering and sub-metering there exists the more information can be extracted out of it.

Ihasalo (2012), on the other hand, created a "Performance monitoring and management system" for building energy consumption data as a part of his doctoral dissertation. The system uses building automation data and transforms it into performance metrics. The metrics are produced by comparing the actual performance to predefined target values that represent acceptable performance. There can be either one or two target values. In the end, the metric is presented in 0 – 100 percentage scale and visualized so that it is easily interpretable. In this specific case the metrics were divided into three categories: energy consumption, indoor condition, and HVAC system metrics. The concept is summarized in Figure 11.

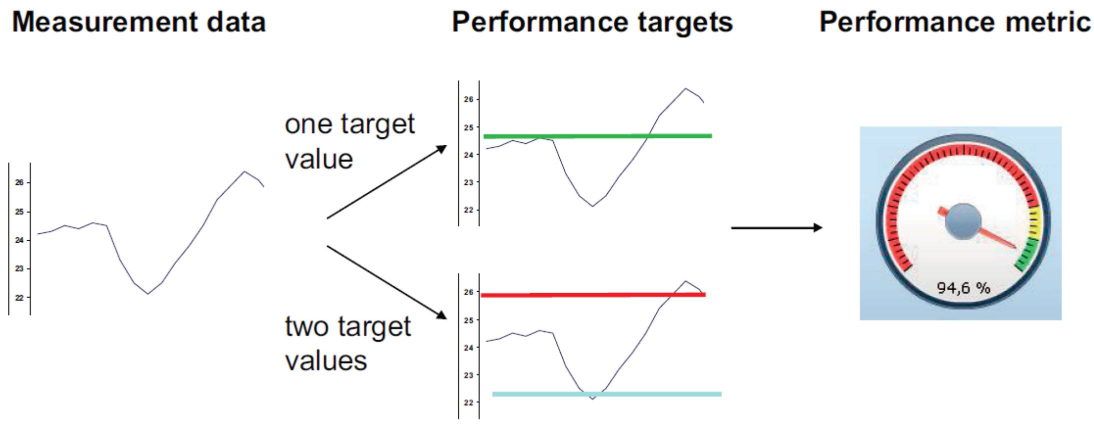

Figure 11. Transforming measurement data into performance metrics (Ihasalo 2012)

By visualizing and making the performance figures easily interpretable, it is also easy to set target for the metrics and follow progress. Moreover, this allows transforming the management targets into concrete and easily understandable goals. The performance metrics can be also linked to operation and maintenance contracts by requiring specific end results instead of defining maintenance actions. (Ihasalo 2012)

2.2.2 Consumption metrics

Forström et al. (2011) started defining energy consumption metrics by taking into account six different factors: embodied energy, consumed energy, recovered energy, built area, utilization rate and quality factor of buildings. The equation with all of these factors is the following:

$$\frac{Embodied\ energy + Consumed\ energy - Recovered\ energy}{Built\ area * Utilization\ rate * Quality\ factor}$$

It was noted, however, that using the equation in reality with all of the factors would result in too complicated way of gathering data and making calculations. A more practical way of defining the metrics would be to use a set of different indicators each made for a single purpose. Those metrics could be then used in combination with each other depending on the objective.

A set of five different energy consumption metrics was proposed (Forsström 2011):

Specific energy consumption (SEC) is a widely used and simple metric where consumed energy is divided with the built area. Area (floor space) can be either heated area or gross area depending in the purpose of the metric. With this metric it is easy to compare buildings regardless of their different sizes. The equation is the following:

$$SEC = \frac{Q}{A} = \frac{Energy\ consumed}{Built\ area} \left[\frac{kWh}{m^2}\right]$$

Specific energy consumption adjusted for utilization rate (SEC_{UR}) takes into account the utilization rate of the building. By taking the utilization rate into the calculations, the buildings that are more effectively used will get better figures. In this case the built area is multiplied with the utilization rate factor which is a percentage figure depicting the utilization of the building. The equation is the following:

$$SEC_{UR} = \frac{Q}{uA} = \frac{Energy\ consumed}{Utilization\ rate * Built\ area} \left[\frac{kWh}{m^2}\right]$$

Energy intensity of usage (EIU) takes into account how efficiently the building usage is by considering the person hours spent in the building. For example, there may be two similar buildings but there is different amount of people working or living in them. Now, the building with are more people will get better rating with this metric. The equation is the following:

$$EIU = \frac{Q}{T_{pers}} = \frac{Energy\ consumed}{Person\ hours\ spent\ in\ the\ building}$$

Many times rent is the concrete utility that the owner of the building is getting by letting it to tenants. **Economic energy intensity** (EEI) compares consumed energy to the rent that is gotten from the building. The equation is the following:

$$EEI = \frac{Q}{R} = \frac{Energy\ consumed}{Rent} \left[\frac{kWh}{€}\right]$$

Energy performance index (EPI) is a benchmarking metric that allows comparing buildings in a way other metrics do not. It compares the actual energy consumption to a similar building built with best available technology (BAT) that is easily available on the market and cost-efficiently implementable. In other words, it tells the energy consumption improvement potential of a building. The greater the value of EPI the greater the improvement potential is. The equation is the following:

$$EPI = \frac{Q_{actual}}{Q_{BAT}} = \frac{Actual\ energy\ consumption\ of\ a\ building}{Energy\ consumption\ of\ a\ similar\ building\ with\ best\ available\ technology}$$

Corgnati et al. (2013) used in their study a bit modified version of the SEC. Instead of built area they used built volume which takes into account the varying room height of buildings. In addition, they multiplied the volume in the denominator with the heating degree-days of the building's location. This way they are able to compare the performance of buildings located in different places. In this case the equation is the following:

$$SEC = \frac{Q}{V * HDD} = \frac{Energy\ consumed}{Built\ volume * Heating\ degree\ days} \left[\frac{kWh}{m^3}\right]$$

The annual whole-building energy use index and energy cost index are also very widely used and they can be calculated as follows (Ihasalo 2012):

$$Total\ Energy\ Use\ Index\ (EUI) = \frac{Total\ Annual\ Energy\ Use}{Gross\ Floor\ Area} \left[\frac{kWh}{m^2}\right]$$

$$Energy\ Cost\ Index\ (ECI) = \frac{Net\ Annual\ Energy\ Cost}{Gross\ Floor\ Area} \left[\frac{€}{m^2}\right]$$

Forström et al. (2011) also pointed out that the selection of particular metrics should be based on predefined goals. It needs to be known why energy consumption and performance is measured and what is made with the information that the metrics provide. The process of applying energy performance indicators is presented in the Figure 12.

Figure 12. Process of applying energy performance indicators (Forström et al. 2011)

ASHRAE (2010) and Ihasalo (2012) divided energy consumption metrics into three different categories depending on the level of detail. The basic level represents aggregate data of building's monthly or yearly consumption. Intermediate data is weekly data of the whole building's energy consumption and demand. The advanced data level provides daily and hourly data concerning the energy consumption. The different levels of data are summarized in the Table 2.

Table 2. Energy consumption metrics based on level of details (Ihasalo 2012)

PROTOCOL LEVEL	DESCRIPTIVE INFORMATION	MEASURES
BASIC	Basic energy-related buildings / system characteristics	1. Monthly and annual whole-building energy, demand and cost 2. Annual whole-building energy use index (EUI) and energy cost index (ECI)
INTERMEDIATE	Specific energy-related buildings / system characteristics	1. One year of monthly and weekly energy demand for whole building 2. Monthly and weekly energy use and targets for major systems and end uses

ADVANCED	Detailed energy-related buildings / system characteristics	1. One year of daily and hourly energy demand for whole building 2. One year of daily and hourly energy and demand for major systems and end uses

2.2.3 Normalization of energy consumption figures

Motiva is a state-owned expert company that promotes efficient use of energy and materials in Finland. They are publishing and freely distributing advice and data concerning standardization of energy consumption data; that is, doing weather corrections to energy consumption data. The normalization is based on heating degree days calculated for multiple cities around Finland.

Degree days are used to calculate the heating (or cooling) need of a building from the outside temperature. In Finland, the Finnish Meteorological Institute calculates and distributes freely the heating degree days (HDD) on a monthly basis for 16 locations around Finland. The values are calculated by adding up the remainders of daily average indoor and outdoor temperatures. HDDs for every other city and municipality in Finland are gotten by using city-specific correction factors. The indoor temperature used in the calculations is 17°C and it is called base temperature. The difference between the base temperature and actual indoor temperature is expected to be covered with building's internal heat loads. (FMI 2014)

Because outside temperature affects the heating need of a building greatly, the consumption figures need to be weather corrected. This process is called consumption data normalization. With the help of heating degree days and consumption data normalization it is possible to perform comparisons between buildings in different locations and different times. Firstly, it is possible to compare building's own consumption between different years or months. Secondly, it is possible to compare buildings that are located in the same region by normalizing the consumption data to the local reference city. Finally, it is possible to compare buildings located anywhere in Finland by standardizing their energy consumption to the national reference city Jyväskylä.

It is important to remember that the energy required to produce domestic hot water does not depend on weather. For this reason it cannot be weather corrected and must be separated from the calculations. The equations and calculation examples are presented in detail on Motiva's web page. (Motiva 2014)

2.2.4 A summary of performance monitoring

Energy performance need to be monitored to collect the consumption data and that helps to gain an understanding of the condition of the building. Usually IT is utilized to automate the collection process and to visualize the consumption data to make it more easily understandable. Different metrics are used to analyze the various aspects of energy consumption. They can tell about the technical energy consumption or highlight the economic aspects of consumption depending on the selected metric. The most common metric is specific energy consumption (SEC) which is the energy consumed in relation to floor space. Finally, the consumption figures need to be normalized in order to compare buildings that situate in different climatic regions.

2.3 Analyzing a portfolio of buildings

This section discusses analysis methods found in the literature that are useful in analyzing a large portfolio of buildings. Some of them are statistical in nature, such as frequency distribution or linear regression while others are more qualitative analysis methods. In addition, the advantages of categorizing buildings and using qualitative analysis methods are explained. In the end of the section, target setting for energy performance and how the improved performance can be verified are considered.

Traditionally there has been a stronger focus on monitoring and analyzing the energy consumption of a single building compared to analyzing a building stock. However, in order to achieve a large impact in energy saving initiatives, it is needed to widen the scope to study a building portfolio rather than a single building. (Fracastoro 2011)

RIL (2009) performed research to get a general understanding of the order of magnitude of the specific energy consumption in the Finnish building stock. According to them, the yearly specific energy consumption of building's heating system for a building built with 2010 norms is roughly 130 kWh/m^2. On average, 35 kWh/m^2 of this consumption is formed when domestic hot water is heated. The electric energy consumption of the property and households is assumed between 20 and 40 kWh/m^2 which makes the total energy consumption of a norm building to 150 – 170 kWh/m^2. As a comparison, the total consumption of a low energy building is 78 – 115 kWh/m^2 of which 48 – 80 kWh/m^2 goes to heating and 30 – 35 kWh/m^2 to electric energy.

The heating energy consumption of Finnish buildings connected to district heating has been declining within the last ten years from value 230 kWh/(m^{2}a) to 150 kWh/(m^{2}a) on average. Major part of this decline is due to changes in the building code. There has been changes to more demanding energy efficiency solutions in the years 1978, 1985, 2003, 2007 and 2010 (RIL 2009). Even though there has been positive development towards more efficient buildings, there are still many possibilities to improve the efficiency further. For example, a study discovered that in EU and in Finland cost-effective savings of 10 % in heating energy consumption could be achieved by 2020 and savings of 20 % by 2030 (Tuominen, Klobut et al. 2012).

2.3.1 Frequency distribution

One of the simple ways to get an overview of the energy consumption of a building is to create a histogram (or frequency distribution) of the energy consumptions figures. In the histograms, specific energy consumption in relation to either floor space or heated volume is used most commonly. For example, Corgnati, Corrado et al. (2008) created a frequency distribution of normalized specific energy consumption (Figure 13) of the buildings in their study concerning Italian schools. It revealed that majority of the formed a distribution that reminded a bell-curve and that most of the buildings have reasonable energy consumption. However, it was noticed that there is a long tail of buildings and they are consuming significantly more energy per heated volume compared to the majority of buildings.

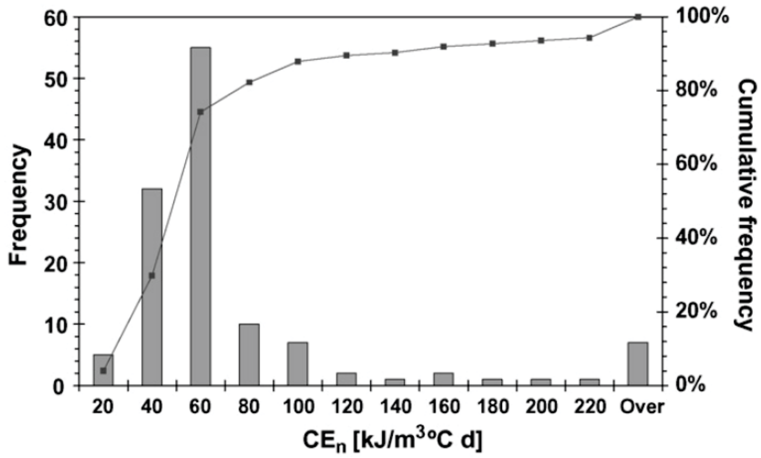

Figure 13. An example of a frequency distribution of specific energy consumption (Corgnati, Corrado et al. 2008)

In another analysis, Corgnati, Corrado et al. (2008) plotted the frequency distribution according to heated volume (Figure 14). Now, it was noticed that despite the fact that the frequency of buildings with small volume is high, their share of the total billed energy consumption is not significant. This implies that it is more effective to start reducing the energy consumption from the largest buildings in order to get an immediate impact on the energy consumption of the whole building stock.

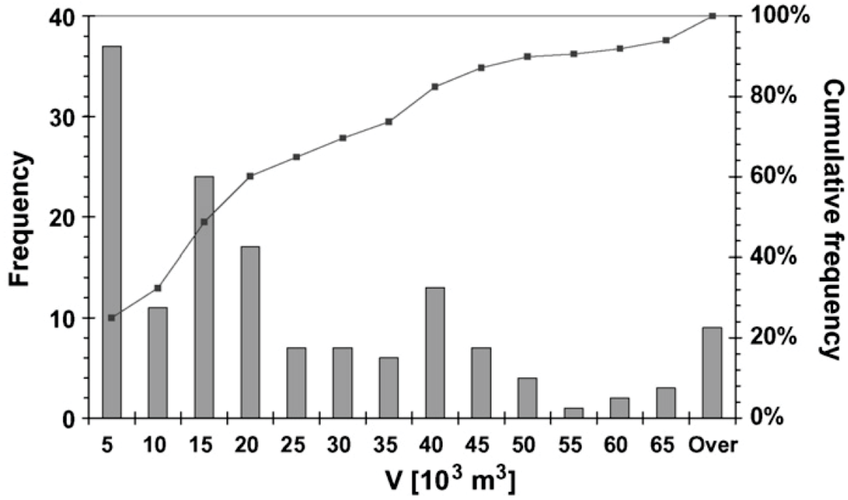

Figure 14. Frequency distribution of SEC based on heated volume (Corgnati et al. 2008)

The results of the analysis by Corgnati, Corrado et al. (2008) revealed that the frequency distribution of specific energy consumption shows a regular profile around the mean value (i.e., resembles a normal distribution). If the deviation of that profile is high, it implies that the energy performance of the building stock is not homogenous (which was the case with the Italian schools). It was also noted that the results of the statistical analysis can be used as a benchmark in the energy performance classification of a building stock. The conclusions of the study was that the analysis proved to be a simple and flexible method. The method can be used to analyze the energy features of the building stock, provide a cost basis for energy service contracts, and help in planning retrofit measures. The method is particularly suitable for long term assessment of a large building stock. (Corgnati, Corrado et al. 2008)

Also Fracastoro (2011) created a frequency distribution of buildings located in an Italian region. From the distribution figure it is easy to see how the consumption of buildings with different ages perform compared to each other. He stated that especially the effect of new energy laws can be seen in the consumption figures of newer buildings. The frequency distribution can be seen in Figure 15.

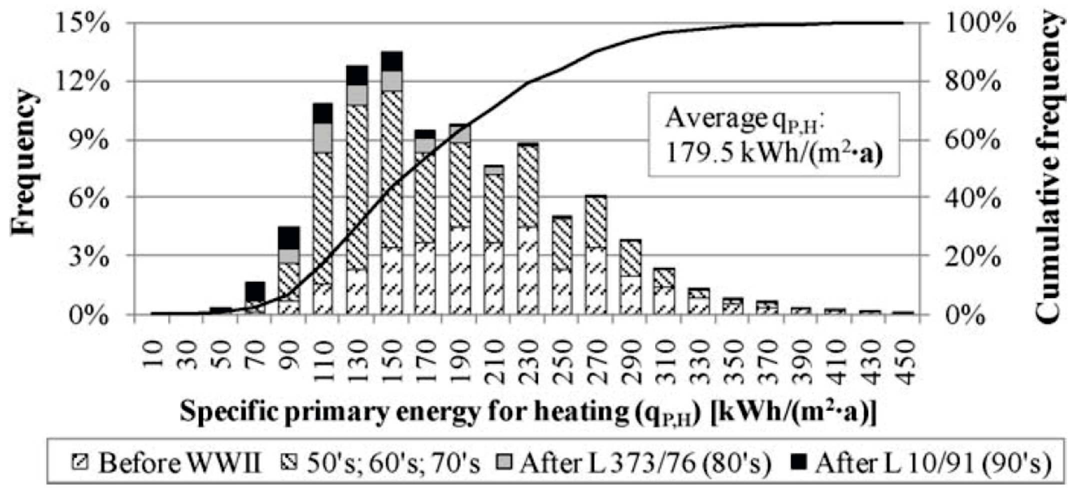

Figure 15. Frequency distribution based on age categories (Fracastoro 2011)

2.3.2 Statistical analysis of building energy consumption

In addition to frequency distributions, many other forms of analysis were performed in the literature. Several of these analyses included the usage of heating degree days but also surface to volume ratio was used.

Fracastoro (2011) created an analytical method to determine the statistical distribution of residential buildings according to primary energy consumption for heating purposes. One of their aims was to help a legislator to create building energy performance certification scale. Quite simple data, such as specific energy consumption, surface area, and degree days were used in the analysis. Multiple different variables were used in the analysis to categorize buildings. These included variables, such as number of floors, number of dwellings per building, age category, heating system efficiency, and number of degree-days. The usage of easily-available data and variables simplifies the data collection process and makes the analyses easier to perform. The statistical distribution was used to create a performance scale, to evaluate the building volume belonging to different classes and to assess how different buildings perform compared to each other. What is more, the energy saving potential of large retrofits to building envelope was evaluated.

In the Figure 16, the correlation of specific energy consumption and degree-days were analyzed by making a scatter plot. From the best-fit curve it is easy to see how different locations are performing compared to each other. For example, the buildings below the curve are performing better than average, while the buildings above the curve are using more energy with the same amount of heating degree days. In addition, it can be seen that in this case the energy usage increases exponentially when the need for heating increases. (Fracastoro 2011)

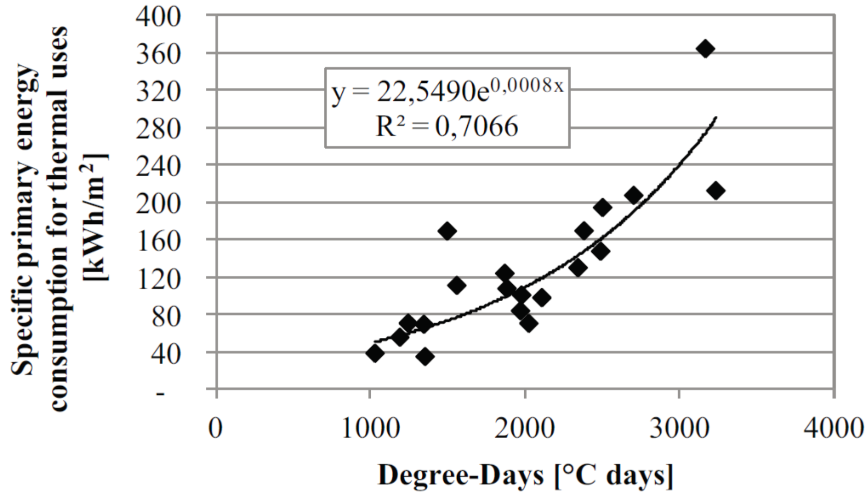

Figure 16. Correlation of SEC and HDD (Fracastoro 2011)

Dall’O’, Galante et al. (2012) analyzed the energy consumption performance of an Italian town with the help of surface to volume (S/V) ratio. They plotted the regression lines that related energy consumption and S/V ratio for different construction periods. It is easy to determine from the analysis how buildings with different ages and surfaces performed against each other. The Figure 17 is an example of this. From the figure it is easy to discover that the buildings with more surface area compared to building volume consistently consumes more energy. It can be also seen that newer buildings consume substantially less energy compared to the older buildings. This implies that it is most energy efficient to build new buildings with large floor space which leads to smaller surface area.

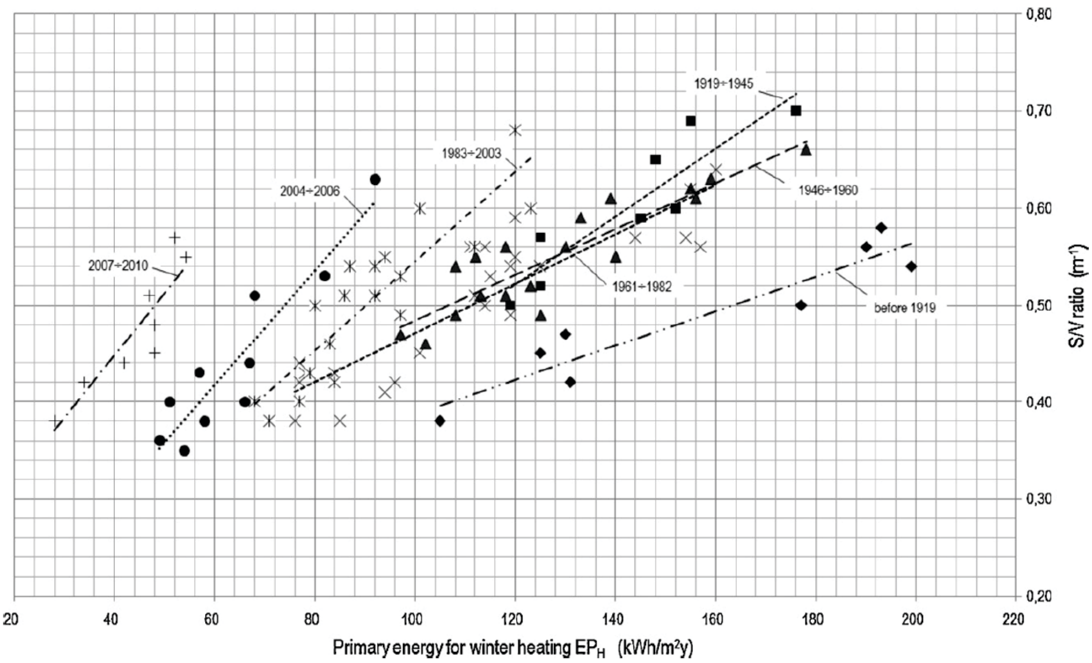

Figure 17. Regressions of SEC and S/V ratio (Dall'O’, Galante et al. 2012)

Theodoridou, Papadopoulos et al. (2011) performed statistical analysis on the Greek residential building stock. They studied in the analysis how building age, floor area, number of inhabitants, window type, and attachment to other buildings correlated with energy consumption. According to them, newer buildings tend to perform better compared to older ones. What is more, better windows resulted in significant energy savings. What they also noticed was that households with higher income tend to consume more energy compared to households with smaller income.

Corgnati, Corrado et al. (2008) performed statistical analysis on a building stock concerning 120 Italian schools. The aim of the study was to provide an energy performance indicator for each building. With the help of the energy performance indicator it is possible to find the buildings that are consuming considerable amounts of energy and are in need of thorough energy diagnosis. In the analysis, they used the energy consumption data of the buildings, geometrical data, and operational periods as well as climatic data in the form of heating degree-days. They noted that to have enough statistical data, the data collection period should be at least three years. In addition, the data should be uniform and comparable so that reliable analyses are possible. Thus, the climatic variation needs to be cleared from the energy consumption data. Using the heating degree-days were discovered as suitable way to neutralize the effect of the climate to the energy consumption. One of the first analysis performed by Corgnati, Corrado et al. (2008) was a frequency distribution of the heated volume. Next, an assumption of a linear correlation was verified between monthly specific energy consumption and monthly heating degree-days. An illustration of this correlation can be seen in Figure 18.

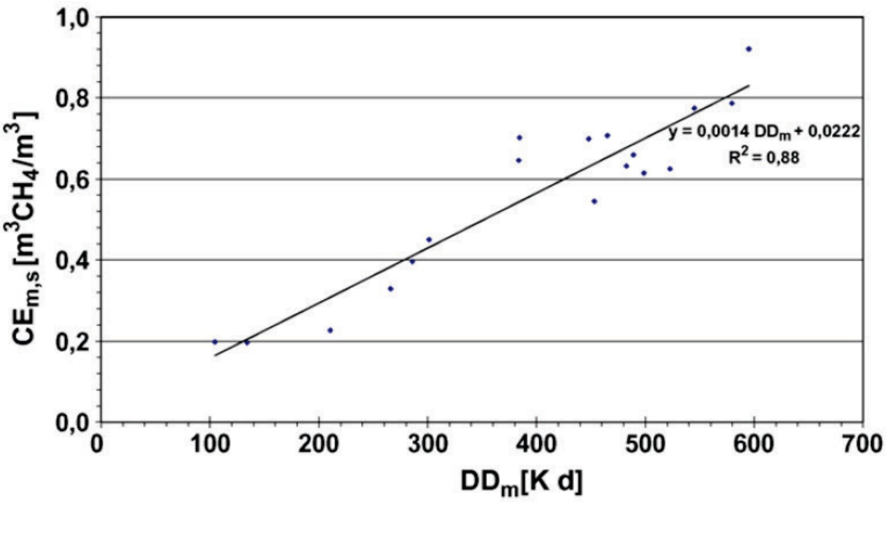

Figure 18. Linear correlation of SEC and HDD (Corgnati, Corrado et al. 2008)

As can be seen above, many studies use the help of different regression models to analyze energy consumption. Frequently, heating degree days are used in the model because heating energy consumption is dependent on the outside temperature. For example, in an IBM research report a multi-step statistical analysis procedure was developed to analyze energy consumption and to identify savings opportunities in a large building stock. The analysis procedure used the combination of Variable Base Degree Day method as well as different regression models. In the first step of the procedure they created energy performance scores for the whole building portfolio and benchmarked them. In the second step, they separated the base load energy consumption from the weather dependent consumption. Thirdly, they conducted root cause analysis which allowed them to create performance scores for base load, heating and cooling separately. Finally, they modelled the error structure to forecast and detect abnormal energy consumption. (Liu 2011)

In a bit more straightforward study, Capehart, Turner et al. (2006) noted that the energy needed to maintain a building temperature is approximately equal to the heat losses through building envelope and HVAC systems. This energy correlates with the difference between the inside and outside temperatures. A linear regression model could be formed to illustrate this relation. The model was called Energy Performance Model (EPM). Basically same analysis compared to the EPM was introduced in an article by Degreedays.net that used degree days to make a linear regression analysis of energy consumption data (BizEE 2014). In the analysis, monthly HDD and heating energy consumption are used to create a scatter chart and a fitted regression line for the points. The form of the equation for the linear regression line is y = ax + b. In the equation, the number before x is the gradient of the trend line and the constant b is the intercept where the trend line crosses the y axis. In the figure, energy consumption is on the y-axis and HDDs are on the x-axis. R^2 is the correlation coefficient which tells how well the data points fit on the trend line. The closer the value of R^2 is to 1.0 the better the correlation. Values above 0.75 can be considered acceptable. An example of the data points and the regression line can be seen in the Figure 19.

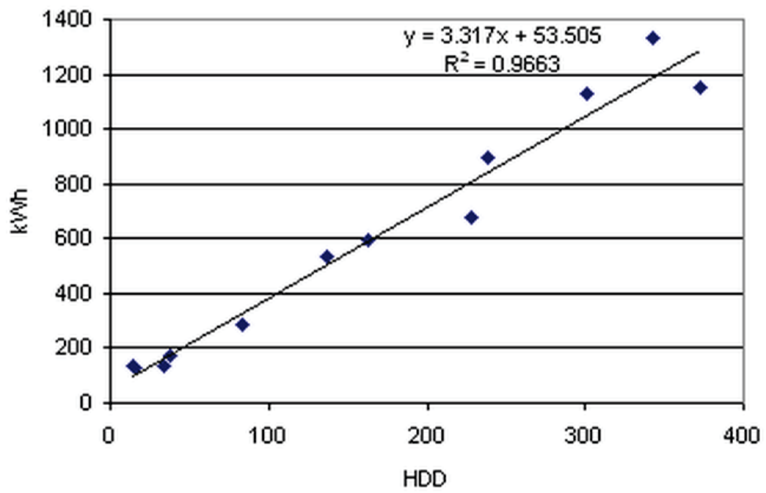

Figure 19. An example of a linear regression of HDD and energy consumption (BizEE 2014)

With the equation it is possible to estimate the heating energy consumption with a given HDD or estimate the HDD with a given heating energy consumption. For example, it can be used prior and subsequent to an energy efficiency improvement investment to track whether the efficiency really improved or not. Another useful aspect is the constant b which is the intercept. It tells the base load (i.e., the energy consumption) of the building that is not related to outside temperature. Also Liu (2011) identified that that the base load should be separated from the other consumption when doing analyses. Usually, in residential buildings, this means mainly domestic hot water usage when it is heated with the same system as the building.

Another useful technique related to the linear regression model is to analyze the energy consumption by using Cumulative Sum of Differences (CUSUM). Capehart, Turner et al. (2006) suggested that the statistical CUSUM technique is a central part of energy monitoring, targeting and reporting. This technique analyses the variance between the actual energy consumption and the consumption predicted by the linear regression model. The first task in CUSUM is to define a baseline to which the forthcoming energy consumption data points will be compared. The baseline is usually formed from a time period of consistent performance prior to any energy efficiency retrofits. The CUSUM analysis itself is very straightforward to do. Predicted energy consumption values are calculated with the help of the baseline linear regression model and heating degree days. Next, variances are calculated by subtracting the predicted consumptions from the actual energy consumptions. Now, the CUSUM is the sum of these variances and the data points can be plotted as time series to make it easier to interpret.

If the CUSUM value stays near zero the process is in balance, i.e., there is no significant change in either direction. On the other hand, if the CUSUM values starts to deviate permanently from the zero, the energy consumption has increased or decreased compared to the baseline model. Below, in Figure 20, is an example of a CUSUM graph which illustrates permanently reduced energy consumption from the week 15 onwards. However, the CUSUM graph does not tell anything concerning the reasons of the change. To discover the reasons, other analysis methods need to be used.

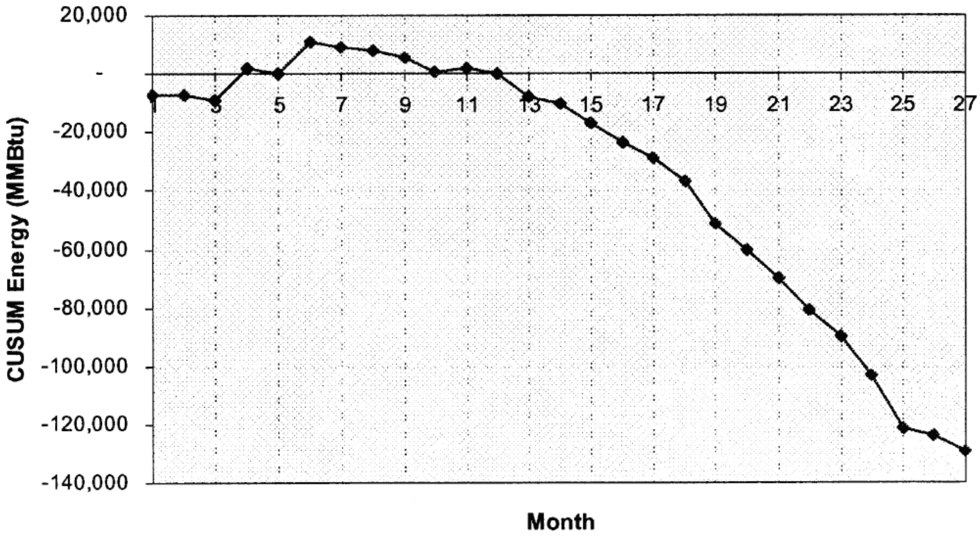

Figure 20. An example of a CUSUM chart (Capehart, Turner et al. 2006)

2.3.3 Creating a building typology

Using building typologies is a convenient method to make a large building stock easier to study. Creating building typologies means that buildings are classified into different categories according to the characteristics that are related to the energy performance of the building. These characteristics include factors such as building envelope type, building age, outdoor weather conditions, size of the building, and HVAC systems that are used in the building. (Dascalaki, Droutsa et al. 2011)

Subsequent to categorization of the building stock, a reference building (RB) is chosen to represent the whole category. According to the Energy Performance of Buildings Directive (EU 2010) of European Union, reference buildings *"are characterised by and representative of their functionality and geographic location, including indoor and outdoor climate conditions"*. In general, *"reference buildings aim to characterize the energy performance of typical building categories under typical operation"* (Corgnati, Fabrizio et al. 2013). The study identified four areas under which the data can be gathered for creating the reference buildings: form, envelope, system, and operation. Form category includes the type of the building (residential, commercial) and general geometrical data such as surface. Envelope category, on the other hand, includes data concerning the materials used in building and their thermal properties. The third group, system, consists of heating, cooling and ventilation systems as well as renewable energy systems in the building. The fourth category, operation, consists of operational parameters that affect the usage of the building, such as ventilation and heating schedules. (Corgnati, Fabrizio et al. 2013)

Dascalaki et al. (2011) studied Hellenic buildings and how building typologies could be exploited in energy performance assessment of a building portfolio. They identified that building typologies can be used to gain an in-depth understanding of the energy consumption of a building stock. In the study, buildings were categorized according to the building age, size, and climate zone. This categorization resulted in 24 different classes, and each class was assigned a real example building. Subsequent to the categorization, two retrofitting options were suggested for each category, and the energy efficiency improvement potential was evaluated. The strength of the building typology approach is that it simplified the process of evaluating the energy efficiency improvement potential and quickly demonstrates the impact of possible energy conservation methods.

Creating building typologies was the core of a research project called TABULA (2014). The objective of the TABULA project was to create categorized building typologies for European building stock in order to estimate the energy demand of buildings on a national level and to predict the impact of energy efficiency improvements in the building stock. In the TABULA project, buildings were categorized by building age, size, and climatic zone. For example, in Sweden the buildings we categorized in three climatic zones, five age groups and then either to single or multifamily houses. This resulted in total to 30 different building categories. Subsequent to the categorization, an example building was selected which represents the whole building category. In addition, supplementary sub-typologies were prepared depending on what kind of HVAC systems were used in the buildings. What is more, TABULA calculated examples to demonstrate how refurbishment can affect energy consumption. Three variants were prepared for each building. The first, "existing state" shows the typical state of non-refurbished building. The second, "usual refurbishment" takes into account some common refurbishment methods focused on upgrading the building envelope and heating system. The third "advanced refurbishment" included measures to the envelope and heating system that are only used in very ambitious projects. (TABULA 2014)

Ballarini, Corgnati et al. (2014) stated that because a large building stock is usually heterogeneous, the buildings need to be divided into categories. This will help in analyzing the consumption and creating refurbishment recommendations. An investigation procedure to improve energy efficiency was suggested:

1. *"energy performance calculation of the reference buildings to assess the baseline of the energy performance*
2. *definition of sets of energy retrofit measures to be applied to the reference buildings*
3. *energy performance calculations to evaluate the energy performance after the retrofit measures*
4. *calculation of the life cycle costs using net present valuation*
5. *finally, assessment of the cost optimal (and cost-effective) set of measures to optimise (and increase) the energy performance of the reference buildings"*
   (Ballarini, Corgnati et al. 2014)

In the TABULA project, three different methods were suggested to categorize the buildings. The first, "Real Example Building" approach uses experts' experience to determine the categories, such as climatic, and age. This is used when no statistical data is available from the buildings. The second, "Real Average Building" approach identifies the example building for a category by using statistical data. A real example building is searched from the category so that the characteristics of the building represents the average values in the chosen category. The third, "Synthetical Average Building" approach creates an artificial building that represents the average properties in the building category by using statistical methods. (Ballarini, Corgnati et al. 2014)

According to the TABULA project, the building typologies can be considered as a starting point for the assessment of energy consumption in (national) housing sector. The creation of building typologies allows performing energy performance calculations only with the example building instead of extensive calculations with the whole building stock. Subsequent to recognizing the energy savings potential of the example building, the same potential can be assumed to exist in the whole category of similar buildings. This gives a reasonably accurate estimate for the whole improvement potential in the building stock. (Ballarini, Corgnati et al. 2014)

2.3.4 Qualitative analysis of energy efficiency

Qualitative analyses can reveal important facts regarding the energy consumption of a building in contrast to purely quantitative analyses. Therefore, also qualitative methods should be used in the studies. One method of performing qualitative analysis is to create a checklist that is used in the energy assessment phase. When a high-consumer is identified from the building stock, a checklist is used to get deeper understanding of the individual building. For example, Zhivov, Pietiläinen et al. (2009) identified a checklist as a powerful method to find the energy inefficiencies and waste in buildings.

Also Juan et al. (2010) exploited checklists when they created a decision support system for building renovation in their study. One of the features of the system was a checklist for improvement actions for different areas of the building. The different improvement actions were then scored according to the improvements they made. By having a pre-defined and systematic list that was organized according to different categories (e.g., water-efficiency and electricity-efficiency) it was easy to evaluate all possible improvement actions and select the most suitable ones for each case individually.

Another way of gathering qualitative data from a building is to interview people that work with the specific building the most, such as the tenants or the maintenance personnel (Zhivov, Pietiläinen et al. 2009). Interviews can reveal valuable and otherwise hidden knowledge of the performance of the building. A similar method was used by Dall'O', Galante et al. (2012) when they conducted an on-site survey with the help of checklists. The aim was to determine the energy efficiency of buildings by interviewing the residents (among other analyses). In the survey, auditor collected information concerning the need for retrofits, the improvements that have been made already, and possible constraints that might limit retrofitting.

2.3.5 Target setting and performance verification

Goal setting is essential for successful energy management. Goals that are set need to be tough but achievable, measurable, and specific. A deadline is also needed to accomplish the goal. Goals, performance metrics, and measuring/reporting system need to be agreed together with the people taking part in the energy management. (Capehart, Turner et al. 2006)

Performance goals and targets can be set in multiple ways. Perhaps the most intuitive is to at least sustain the current level of performance. Another approach suggested by Capehart, Turner et al. (2006) is to eliminate the least efficient points. In a building stock these can be the least efficient buildings or in a linear regression analysis of individual building these are the data points that are above the regression line. Third strategy is to analyze the base and incremental loads in the regression model and think what could be done to improve those. Next, a new regression model can be formed as a target. Capehart, Turner et al. (2006) also suggested defining the best historical performance as the target. This may not be practical with older buildings since it would require that consumption data is available from the beginning of the history of the building. However, one could take the intended energy consumption of the building as the target. Furthermore, CUSUM graph is suitable also for performance tracking. It is possible to define and plot upper and lower limits to the graph making it a control graph. This is a suitable tool for real time consumption monitoring to see whether goal is approaching or not. Capehart, Turner et al. (2006) reminds that no matter what is chosen as the target, it should be reviewed continuously so that savings are sustained and maximized.

When the targets are set and agreed, the next step is to verify that they are really achieved. EVO (2012) defined Measurement and Verification (M&V) as a process where the savings of an energy management program are reliably determined by using different kind of measurements. It is important to note that it is not possible to directly measure savings since savings are actually absence of energy use. Thus, savings are determined by measuring the energy use prior and subsequent to implementation of an energy conservation measure (ECM). Summary of the process is presented in Figure 21.

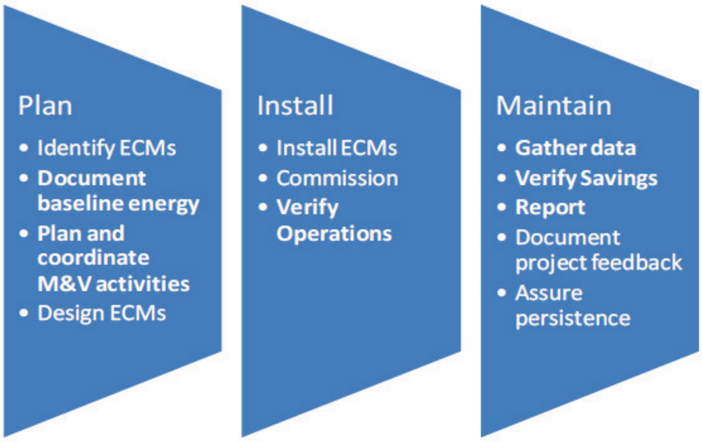

Figure 21. Measurement and Verification process (EVO 2012)

Measurement and Verification process can be used for multiple purposes that are related to energy management. Firstly, it is possible to get valuable feedback from the performance of ECMs whether they have been successful or not. This allows adjusting the energy conservation measures or the future implementation plans of other ECMs. Secondly, it allows more systematic tracking of saved energy and costs because occasionally savings are used for performance-based payments or justification of future investments or financing. Finally, with the data provided by the process it is possible to make more accurate energy budgets.

2.3.6 A summary of analysis methods

This section introduced a number of different methods to analyze the energy consumption of a building stock and a single building. The most useful ways to perform analyses are to create histograms and linear regression models. They are quick to conduct and easy to interpret. In addition, building typologies divides a large building stock into smaller pieces that are easier to comprehend. Analyses are much more rapid to perform because it is possible to do them only with a reference building and then generalize the findings to the whole category. Even though quantitative analyses are vital, qualitative analyses should not be forgotten. It is possible to discover new knowledge with qualitative methods that is not possible otherwise. Finally, after the general state of the building stock is known, it is essential to set improvement targets and verify that they are achieved.

2.4 Economic evaluation of energy saving measures

The economic benefits behind the energy conservation measures are the main reason for many companies to implement them. Thus, it is very important consider it as well. This section introduces briefly methods to evaluate the profitability of energy conservation measures and the life cycle costs associated with them.

Implementing energy efficiency improvements, such as adding insulation, changing the heating system, or adding air heat recovery unit can be an expensive operation. Therefore, it would be optimal if the energy efficiency improvements could be achieved at the same time with other renovations (Tommerup, Svendsen 2006). In connection with compulsory renovations, the energy efficient applications can be implemented cost efficiently. The aim of the conservation measures should be to update the renovated parts as close to a level that corresponds to the requirements set to new buildings (Tommerup, Svendsen 2006). In addition, Dascalaki et al. (2011) noticed that applying energy refurbishments to the whole building stock is not feasible because of the high investment cost. More realistic approach would be to apply the refurbishments only to a certain percentage of the building stock at the same time.

Extensive renovation is not every time rational after all. A study discovered that reducing the energy consumption of an old building to the level of low energy building is rarely economically justifiable (RIL 2009). However, energy renovations can have positive life time value if they are implemented as minor renovations or as a part of other large renovations. Other affecting factors to the desirability of the renovation can be if indoor climate can be significantly improved, energy prices are expected to rise, or the ecological policy of the company requires them. In any case, one of the main goals for energy renovation is to save in future energy costs and improve the life cycle economics of the building. (RIL 2009)

Additional problem is occasionally that energy costs are considered as overhead costs in the accounting processes of a company. This creates problems since people responsible of different areas may feel that reducing overheads is out of their responsibility area. Thus, energy costs should be recognized and billed instead as direct costs from different operating centers. (Capehart, Turner et al. 2006)

2.4.1 Investment profitability analyses

Simple payback period method is a suitable tool to evaluate investments with a shorter lifespan (up to 15 years). However, payback method is not well suited for investments with a longer time span, such as insulation-related measures that have lifetime of 50 – 100 years. Net present value (NPV), on the other hand, is a better method to evaluate the cost-effectiveness of investments with longer lifespan. It also takes into account the interest rate which makes the calculation more reliable. In NPV calculations, the savings and expenses in the future are not valued as much as present values. (Tommerup, Svendsen 2006)

Tuominen, Klobut et al. (2012) used another method when they evaluated the profitability of an energy saving investment by calculating a price for saved energy. This was done by dividing the annualized energy saving investment costs (R) by the annual energy saved (Q_{saved}). The investment costs were annualized for ten years with 10 % interest rate. The equation is the following:

$$P = \frac{R}{Q_{saved}}$$

The price of saved energy was then compared with the local electricity prices to determine whether the investment was cost-effective. However, Tuominen, Klobut et al. (2012) noted that the price for improvement investments will be significantly lower if it is done autonomously; that is, at the same time when renovation would have to be done in any case. While doing the evaluations it is needed to remember that rising (or declining) energy prices can have a major impact on the profitability of the investment. Therefore, it is important to perform sensitivity analysis with different energy prices to see how they affect the profitability of the investment. (Tuominen, Klobut et al. 2012)

Fracastoro (2011) created a simple mathematical model to estimate the effect of large energy efficiency retrofits. The model also suggests the optimal sequential implementation of the retrofits. The basic assumption in the model is that the energy savings will depend on the total amount of investment and the overall energy consumption. The model suggests that the retrofits which have the highest savings to investments ratio (SIR) (i.e., are the most profitable) should be implemented first. In the Figure 22 below it was evaluated how energy efficiency investments affect the yearly energy savings. With the first investments it is possible to get larger savings compared to the later investments (Fracastoro 2011). This common phenomena in investments is called diminishing returns and it is important to remember when implementing considerable amounts of energy refurbishments into a single building.

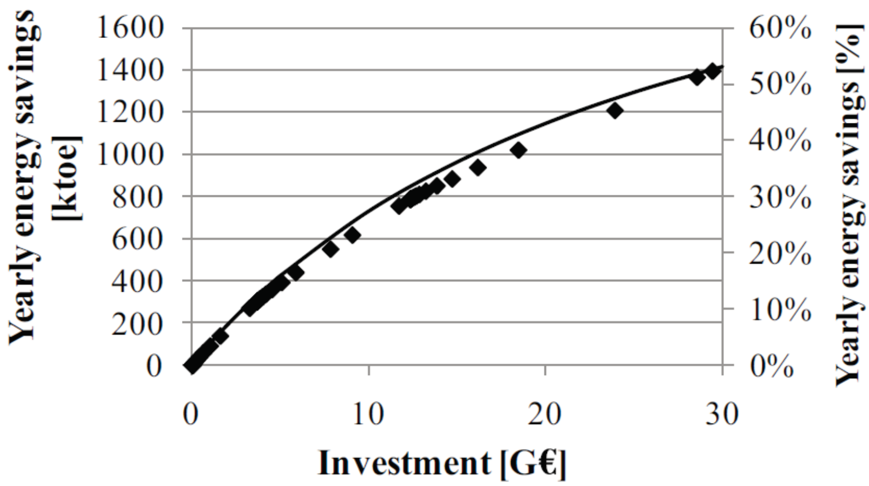

Figure 22. Diminishing returns in energy efficiency investments (Fracastoro 2011)

A similar story concerning the diminishing returns was told by a graphical illustration (Figure 23) that was presented in a study to highlight the cost-effective and cost-optimal solutions in energy saving measures (Ballarini, Corgnati et al. 2014). The figure shows that while investment costs rise linearly, the energy costs savings curve is logarithmic. In other words, the energy cost savings gotten with a certain amount of money (i.e., marginal utility) start to decline subsequent to a certain point.

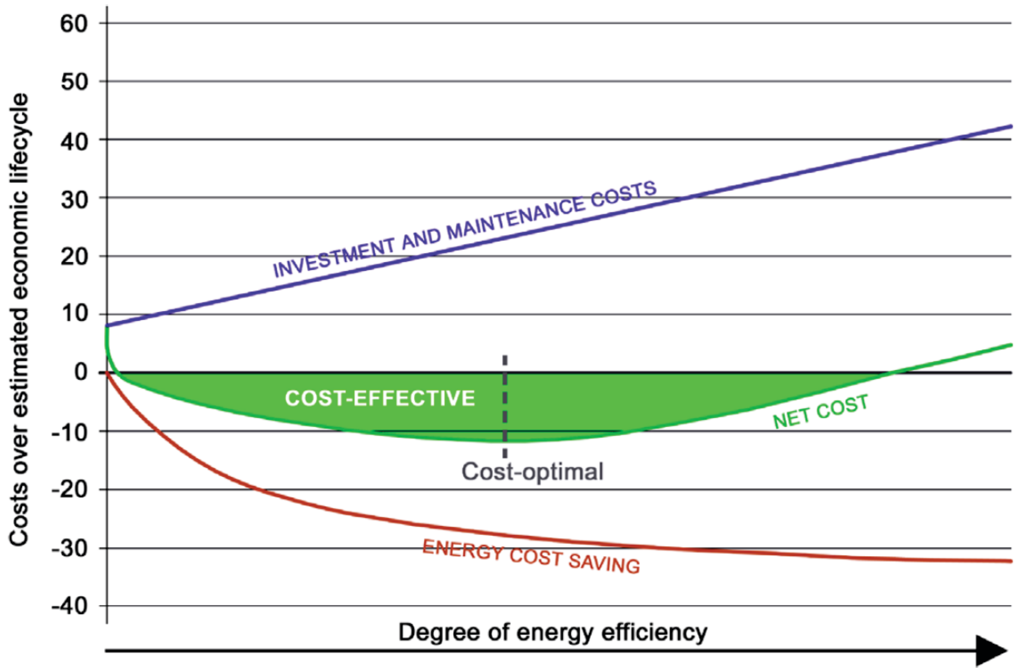

Figure 23. Cost-optimal point and cost-effective range in investments (Ballarini, Corgnati et al. 2014)

2.4.2 Life cycle cost analyses

Ramesh et al. (2010) performed a study concerning the energy use of the life cycle of buildings. The life cycle analysis takes into account the construction, usage and demolition of a building starting from the raw material production to keeping the building warm during habitation until transporting the demolished building materials to recycling. Energies can be divided into embodied energy and operational energy. Embodied energy is the energy that is accumulated into the building materials prior to and during construction whereas operational energy is the energy used during dwelling (heating, cooling, water usage, etc.) and daily maintenance. The study also discovered that operational energy accounts for a major share (roughly 80 – 90 %) of the life cycle energy costs while embodied energy was around 10 – 20 %. The energy used during demolition was negligible. It was also noted that despite different climatic conditions the relationship between operational energy and life cycle energy is nearly linear. Because operational energy consumption produces most of the energy consumption of a building, effort should be focused on reducing this part. Many active and passive ways can be used to increase the energy efficiency of a building, which include better insulation, advanced windows, exhaust heat air recovery, heat pumps as well as solar thermal collectors and photovoltaic panels. Even though using these methods will result in higher embodied energy they will at the same time reduce the operational energy so that the total energy consumption will be lower than without active and passive energy saving methods. (Ramesh 2010)

Another study compared the life cycle energy consumptions of conventional, low energy and zero energy buildings. It was noted that a low energy building performs better than a zero energy building from the life cycle point of view. In zero energy buildings the embodied energy becomes significantly larger compared to low energy buildings. Thus, the life cycle energy usage of zero energy building exceeds that of low energy building. However, the embodied energy of low energy buildings increased only slightly when compared to conventional buildings. The increase stays well below the savings in operational energy making the total energy consumption lower than that of conventional buildings. Therefore, a proper and balanced use of active and passive energy saving technologies may lead to significant improvements in the energy efficiency of buildings. (Sartori, Hestnes 2007)

Martinaitis (2004) mentioned that many times the life time of an investment is not taken into account when the profitability of an investment is evaluated with the simple payback time method. For example, if an investment has a payback time of 7 years it is normally considered as profitable. However, if the life-time of the investment is only 5 years it cannot be considered as a profitable investment. Life-time of an investment has to be taken into consideration also when the payback times of different investments are compared. Another clear limitation of the payback time method is that it does not value the cost of borrowing money. He also introduced a new method to assess the cost-effectiveness of an investment called cost of conserved energy (CCE). It takes into account the investment cost, annual savings, lifetime of the investment, and the discount rate. The benefit of CCE is that it is very easy to interpret. The investment will be cost-effective if CCE is lower than the current price of energy.

The study by Martinaitis (2004) also identified that in many energy efficiency retrofits the energy savings is not the only benefit achieved with the retrofit. Most of the times the investment also rehabilitates some of the building elements and increases the value of the building. The study introduced a coefficient (valued between 0 and 1) which can be used to divide the investment cost to energy saving and building rehabilitation. Because parts of the building has to be renewed periodically implementing energy efficiency investments at the same time makes them more profitable. (Martinaitis 2004)

2.5 Energy Operations Management as the literature synthesis

Many sources that were examined covered similar issues around the central theme of (improving) energy efficiency in buildings. Different processes, measuring methods, management practices, categorization methods, and analysis techniques were discussed from multiple perspectives. Yet, a simple framework could not be found that would combine the different aspects of energy management for a single company with multiple buildings. In addition, another fundamental issues was not addressed well in the literature. In order to keep the amount of work reasonable, it is needed to divide the buildings in to two categories. One which has sufficient energy performance for now and another which requires special attention and more work. This will reduce the amount of work required to improve the performance of the building stock compared to the situation where all buildings are analyzed thoroughly.

Energy Operations Management

A framework was developed to fill the gaps in the literature and it was named Energy Operations Management (EOM). The framework is presented in Figure 24. The EOM framework combines the different aspects related to energy performance as an easily understandable process. It covers issues, such as organization's energy policy, short and long-term targets, energy consumption monitoring, energy waste detection, and implementing energy conservation measures. What is more, the process will optimize the analysis work by focusing effort to only those buildings that need the most attention. By focusing analysis effort, it is possible to increase efficiency and get better payback from energy efficiency investments. Next, the different parts of the EOM are introduced and discussed in detail.

Organization's energy policy, planning and targeting

If there is a want or a need to improve energy efficiency, the organization has to have an energy policy that clearly states the desired objectives. The strategy and specific targets are made based on the policy. The targets can be divided into short-term and long-term targets depending on the level of urgency. Short-term targets and plans are more involved with daily maintenance of buildings, whereas long-term plans include continuous building commissioning as well as educating employees and tenants regarding energy efficiency. The specific energy performance targets are formed together with short and long-term plans. Based on these specific targets it is determined whether single buildings operate within acceptable energy consumption limits. Part of the long-term planning is to follow the development of the average energy consumption of the building stock. When needed, it is important to adjust the targets to maintain a heathy pressure to improve the performance of the building stock.

Routine monitoring cycle

In the routine monitoring cycle, energy consumption data is gathered from every building and it is stored in a central database. Next, analyses are performed to form a detailed picture of the energy consumption of the single buildings and the building stock as a whole. The consumptions of the individual buildings are then compared to the preset energy performance targets to see whether the buildings performs as well as they are supposed to perform. If the consumptions are within the limits, the cycle starts again when new data is available. The continuous process can be turned into a real-time process in the future when real-time energy consumption data is available and suitable IT systems have been developed. Even before that the cycle time can be made faster if monthly or weekly data is available instead of quarterly or yearly data.

Special attention cycle

The special attention cycle starts if a building fails to meet the energy performance targets. An in-depth monitoring is started in combination with analyses about the condition of the building. Also, a more thorough and qualitative energy assessment can be performed to form a detailed picture of the conditions of the building envelope and technical systems. Based on the analyses, the need for renovation is determined. Another way for the energy assessment to get started is through the continuous commissioning process in which some buildings are assessed on a regular basis. Subsequent to the need for energy conservation measure identification, a feasibility check is performed to see that the planned retrofit is economically profitable and within the budgetary limits of the company. If everything is according to the policies of the company, the energy conservation measure is implemented. Finally, in the follow-up phase, the performance of the retrofit is verified. If everything is now within the performance targets, the building will exit the special attention cycle and enter back to the routine monitoring cycle. However, if the energy performance did not improve enough with the first measure, the building will start the special cycle again so that another retrofit can be considered.

The central question

One of the central questions of EOM is asked at the point when building is about to enter either the routine or the special cycle. How to decide whether the energy efficiency or performance of a building is acceptable? As expected, older buildings and the ones located in northern Finland tend to use more energy, which need to be taken into account.

In addition, it may be more profitable to improve the energy efficiency of buildings located in areas with higher energy prices. What is more, the type of technical building systems create some limitations to the energy performance that can be expected of a building. All of these variables need to be taken into consideration when making the decision whether a building needs special attention or not. Later, in the fourth chapter, I will propose a single indicator that will solve this problem.

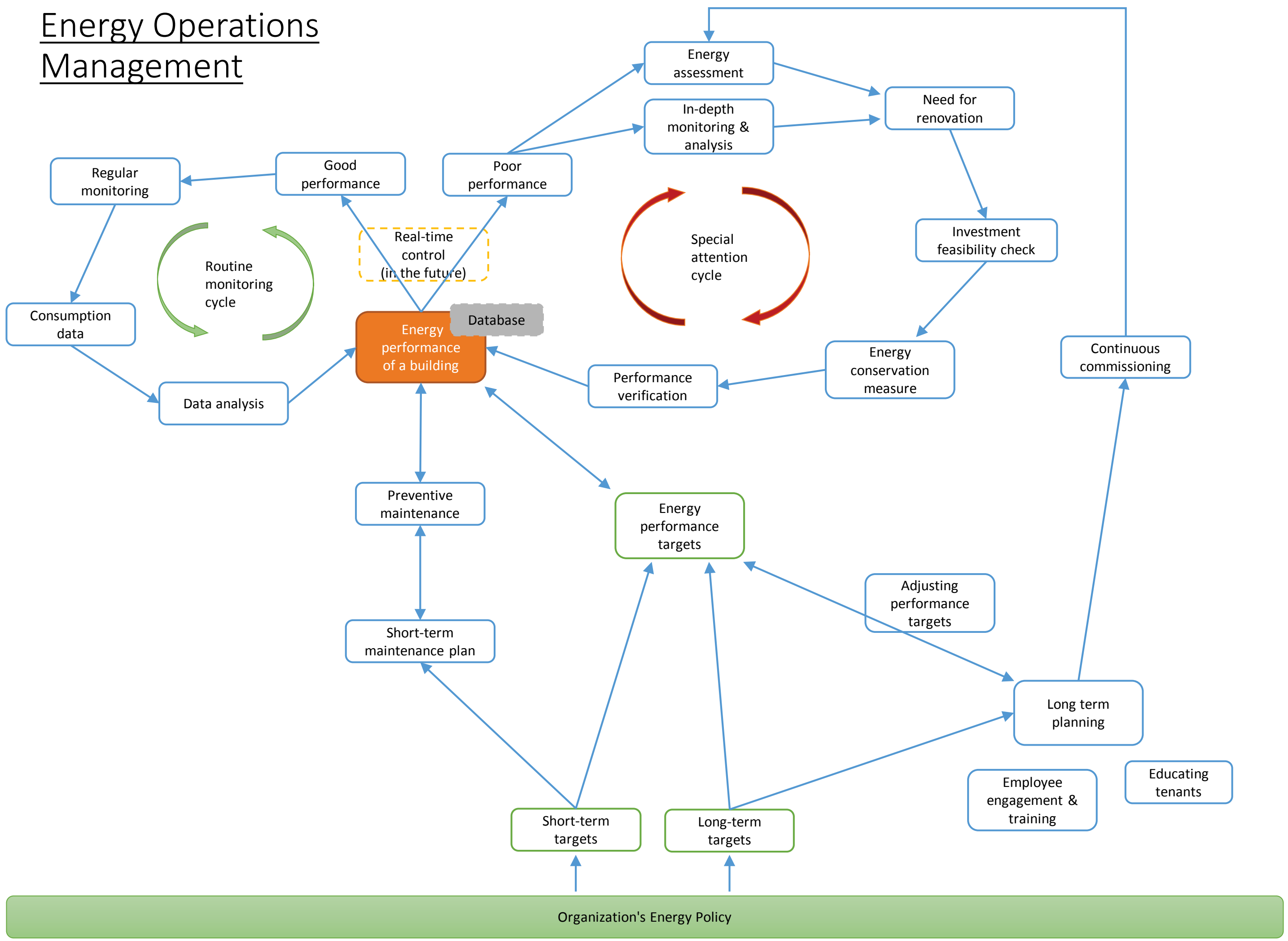

Figure 24. Energy Operations Management process

3 CASE DESCRIPTION

In this chapter, the case company and its building stock are introduced. In addition, it is described how they collect energy consumption data at the moment and what systems they have to process the collected data.

3.1 Introducing the case company

TA-Yhtiöt (later TA) is a national building owner and developer operating in Finland. The apartments they own are mostly right of residence or rented apartments, and they are located in 47 cities or municipalities around Finland. The headquarters of TA is located in Espoo, and local offices are situated in most of the major cities of Finland.

TA has a strong interest and commitment to manage their properties sustainably as well as save in energy costs because energy-related costs are increasing all the time. By increasing energy efficiency TA is able to save in costs and can offer even more affordable apartments for its customers. Therefore, TA wants to further analyze the energy performance of their building stock and improve the methods they are using to cut energy consumption.

Even though there is a strong interest at TA towards energy efficiency, there is no published written statement concerning the targets of energy efficiency improvements that TA wants to achieve. What is more, at the moment, there does not exist a systematic process which TA would follow to achieve energy efficiency improvements. Instead, they are negotiating with several suppliers providing multiple different alternatives for energy saving measures. The challenge is to select the right actions for right buildings from the vast array of possibilities. Thus, there is a risk that the implemented measures are just a set of individual and unconnected actions. Although, it is valuable that measures are taken to improve energy efficiency, it is likely that without a systematic process the greatest benefits cannot be reached.

3.2 Introducing TA’s building stock

TA has a large building portfolio consisting of nearly 13 000 apartments in 500 locations (addresses) around Finland. At the moment, the goal is to produce roughly a thousand new apartments yearly. The total floor space of existing building stock is approximately one million square meters. Roughly half of the buildings are apartment buildings and a quarter is row houses. More details can be seen in the Figure 25. Approximately half of TA’s total floor space is located in the capital region as can be seen from the Figure 26. Second-largest region for TA is Oulu, but also other major cities in Finland have some apartments.

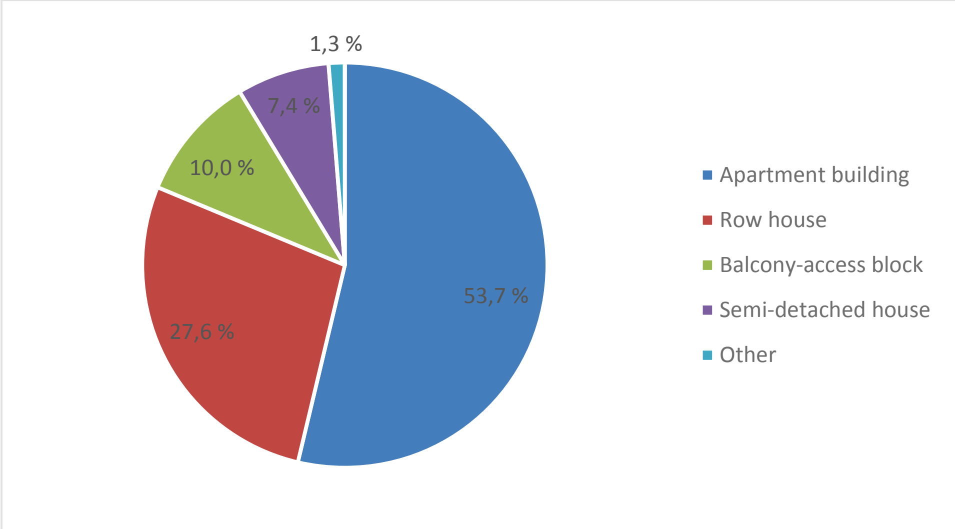

Figure 25. Share of different building types in TA's building stock

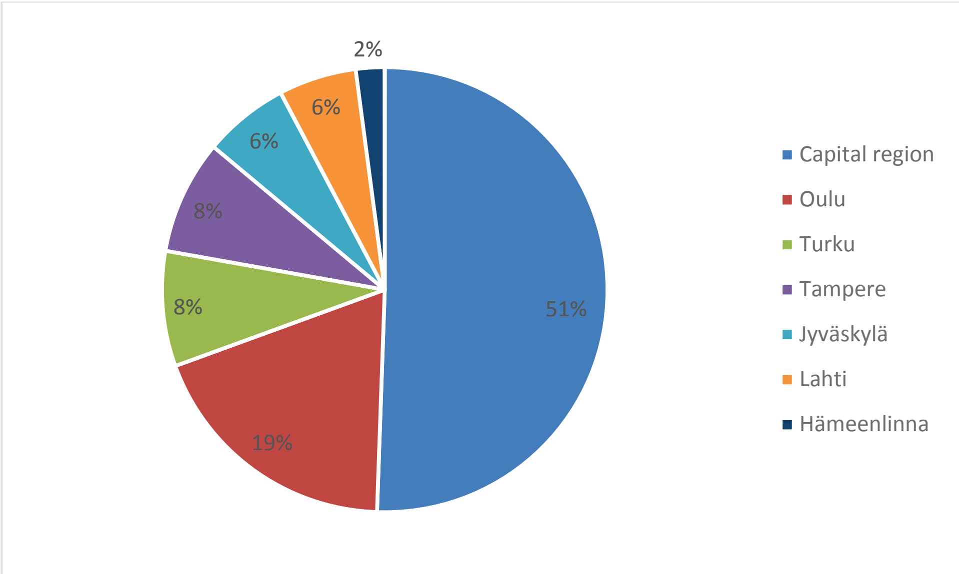

Figure 26. Location of TA's apartments based on building area

A significant part of buildings have been built in the late 1990s as can be seen from the Figure 27. Another construction boom started in 2010 and the brisk pace of constructing new apartments is continuing at the moment. In general, the building stock of TA is rather new which gives a favorable starting point for improvements. In Finland, many of the apartment buildings are built in the 1960s and 1970s which are at the moment and in the near future in need of major refurbishments. Even with renovations it would not be easy to get the energy performance of these buildings to an excellent level. In this sense, having buildings from the 1990s is considerably easier starting point to improve the energy performance of the whole stock.

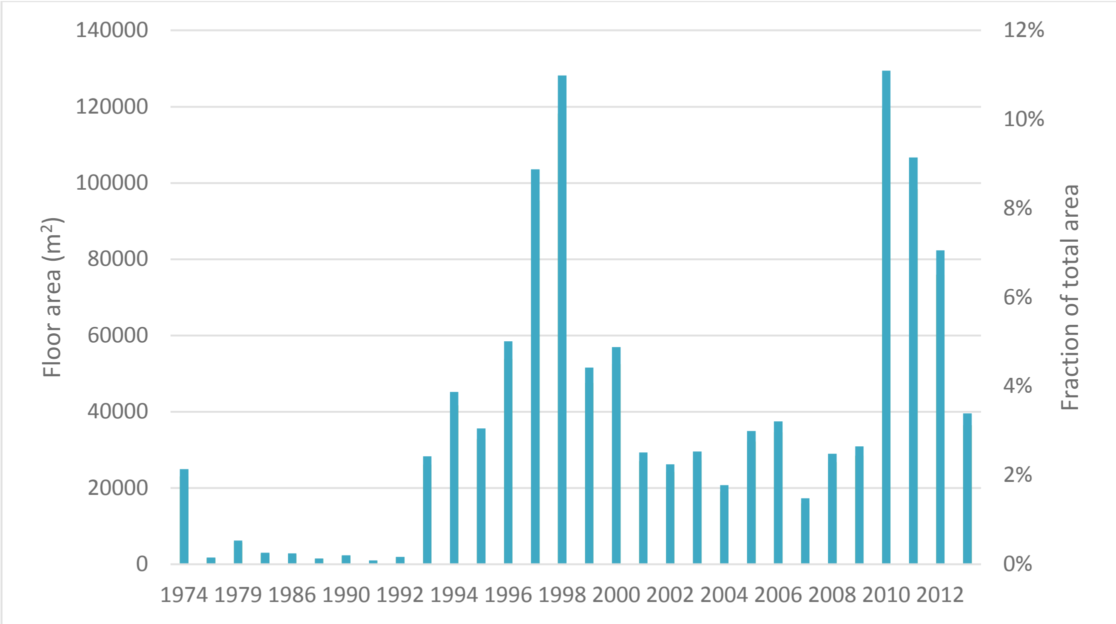

Figure 27. The amount of floor area built in different years

The energy performance of the buildings varies widely depending on the age, type and location of the buildings, but and also depending on the heating method and other HVAC systems. Roughly 90 % of the building stock is heated with district heating. In addition, limited amounts of oil, gas, direct electrical heating, and thermal heat pumps are used. Recently, many oil-boilers have been changed into ground heat pumps which has proven to be a profitable investment.

In the year 2013, TA paid approximately 8 million euros for heating, 4 million for water, and 2 million for electricity. Because of the large scale, even modest savings per square meter of floor space accumulates measurable annual savings. TA pays the heating costs in nearly all of its buildings. The domestic hot water is also included in the heating energy consumption because the water is usually heated with the same system that heats the whole building. The electricity consumed in the apartments is typically paid by the tenants and thus ruled out of the scope. However, the property itself also consumes electricity, and that is paid by TA. The electricity consumption of the property includes elevators, HVAC systems, as well as the lighting of yard and hallways.

Tenants pay rent and/or maintenance charge for TA as a compensation for living in the building. These payments need to cover the energy and maintenance costs, overheads and the profit. Therefore, possible savings from the energy costs enable lower rents for tenants and higher investment possibilities as well as profits for TA.

3.3 Data collection

Consumption data is the basis for analyzing the energy performance of the building stock. To be able to do the analyses not only energy consumption data is needed but also data concerning the basic building characteristics, such as total heated floor space, and the location of the building are vital. Fortunately, due to TA's up-to-date building characteristics database, the basic building data was easy to acquire. Also, accurate financial data on the costs of heating energy, electricity, and water was easy to gather from TA's accounting system.

TA collects four types of energy consumption data in their online property management software called Tampuuri. These four types are district heating energy [MWh], district heating water volume [m^3], electrical energy [kWh], and cold water consumption [m^3]. This data is collected by the property maintenance company responsible for the specific building. The maintenance personnel are reading the consumption meters on monthly basis at the boiler room of the building. Next, the consumption figures are written down on a notebook and afterwards, at the office of the property maintenance company, the figures are updated to the online software. Monthly consumption data collection has been in operation since the beginning of the year 2012. Consumption data from years 2009, 2010 and 2011 have been collected earlier on a spreadsheet.

Accurate and error-free consumption data is the basis for successful energy performance calculations. However, acquiring correct data has caused some problems. Therefore, extensive data validation and correction process have been carried out to acquire faultless data for the calculations of this thesis. Consumption figures of different years were compared to the previous and following years to see whether the change was rational. In addition, heating and electrical energy were compared to the floor space while water consumption was compared to the amount of tenants to see if the consumption figures were within rational limits. The irrational figures were revised with the help of data gotten from the property maintenance companies and energy supplier companies.

The amount of manual work in the consumption data collection is most likely the major reason for errors in the data. Because the consumption figures are manually read and written on a notebook, there is a great chance for human errors. In addition, updating the numbers to the right place and in right way in the online software has also proven to be one source of errors.

Electric energy consumption meters have been changed over recent years to meters that can be read wirelessly by the energy companies. This has made it more difficult to read the consumption figures manually from the meters at the site. In addition, some meters have multipliers meaning that they show the consumption, for example, 20 or 40 times lower as it is in reality. This needs to be taken into account individually meter-by-meter at the online software to get the consumption data right. Therefore, especially the electric energy consumptions have been many times wrong in the online system and correcting them has been time-consuming.

It would be most likely possible to reduce the amount of errors by automating the energy consumption data collection. It would be possible to implement already with the electric energy consumption since all of the meters are wirelessly readable. However, changing into automated data collection would require investments into new software. District heating and cold water meters, on the other hand, are mostly relying in older technologies and it is not possible to read the meters wirelessly. Even if the meters would be wirelessly readable, a standardized way to transfer the collected data from the energy and water companies to TA would need to be developed. Again, this would require significant software infrastructure investments and it has been found too expensive compared to the benefits. One last possibility for TA would be to change the district heating and cold water meters to ones that can be read wirelessly. Also this possibility has been judged to be too expensive.

Another possible solution that has been thought at TA would be to automatically read the consumption figures from the electronic invoices. Approximately 70 % of all invoices at TA and even larger fraction of energy invoices are received electronically. However, the automatic processing and collection of the consumption figures would again need a development of a new system. In addition, the water consumptions are still billed in worst case on a yearly basis which is not enough for continuous consumption metering.

3.4 Different systems at TA related to energy efficiency

Tampuuri is the online building information management software that TA uses for property management and to manage basic building information, tenant information and energy consumption data. It is a daily tool for building managers while property maintenance companies use it on monthly basis to store energy and water consumption data.

TA’s accounting software is called Kiira and it is made by a software company called Pandia. All cost and accounting data is processed there and also all energy and water bills go through it. Kiira allows also the comparison and raking of properties based on cost information. For example, it is possible to rank properties based on energy consumption cost per square meter and building year. The only downside is that Kiira and Tampuuri does not work together which makes it impossible to combine the up-to-date consumption data and cost information to perform analyses within the software.

Pandia recently launched a new feature to Kiira called ‘Pandia Investment’. This feature allows property managers to manage and track investments made to properties and apartments. Another totally new solution that Pandia is working on together with another company called Si-Techno is related to energy saving. With the help of apartment specific thermometers software analyzes the heating energy consumption of the building and optimizes it by leveling the temperatures of different apartments.

TA recently agreed with Eneron to pilot their cloud software called ‘Eneron Online’. Eneron Online is a tool to manage large building stock energy efficiently. It processes building information, energy and water consumption data as well as energy costs and provides analyses on the state of the building stock. It also suggests various improvement actions and calculates the profitability of the investments. Eneron’s solution is quite similar to the EOM process. It has most of the steps that are in the two cycles of the process. However, the buildings that need special attention has to be chosen manually because Eneron Online does not automatically suggest them.

Already at the moment some of TA's newest buildings have building automation systems that can be managed remotely. In the future, it is very likely that this kind of automation system will be common in most of the new buildings. This will create yet another system which needs to be taken into account when evaluating energy efficiency measures to buildings. Remotely controlled automation system is advantageous in that sense that it is easy to see whether all HVAC systems are working as they should be. It will also create alerts in case of malfunctions.

Increasing amount of collected data and the diversity of different systems in use is clearly causing complexity in managing data for TA. As a result, information regarding a single building is stored and must be accessed in multiple places. In addition to different databases and software, Excel spreadsheets are used to store information, such as implemented energy conservation measures. It would be easier to access and process all of the information if it would be stored in one place. This would enable the employees to have a better understanding concerning the condition of a single building. The downside of a single information storage is that it creates a deeper dependency on a single supplier or system. Moreover, it would probably incur considerable amounts of costs to transfer all data into a single place. But, in the long term, it would be most likely that a single system is more cost effective compared to multiple different systems. Transition to a single information management system would presumably produce also indirect savings, such as saved time and reduced errors although these savings are hard to estimate or quantify.

4 ANALYZING THE BUILDING STOCK

This chapter starts by analyzing the present state of TA's building stock. Next, examples are presented about how the EOM process can be utilized for TA's purposes to arrange their energy efficiency improvement actions better. Examples of routine monitoring and special attention cycles are also presented. In addition, a new performance indicator is suggested that can be used to detect whether a building needs special attention and further analyses.

4.1 Present state analysis

This section introduces the current state of TA's building stock. The general consumption of the stock is presented with the information about the age of the building stock. In addition, how the performance of the building stock has been developing during last years is presented.

The Pareto principle applies also in the field of energy consumption of a building stock. According to the principle, only a fraction of the building stock composes most of the total energy consumption. Therefore, the major effort should be used to find and analyze those individuals with high energy cost and consumption. A histogram is a convenient way to quickly get an overview of the specific energy consumption of the building stock as well as to reveal the few buildings that are not performing well. A histogram of TA's building stock is presented in the Figure 28. Specific energy consumption (SEC) is calculated for buildings with district heating, oil boiler, thermal ground heat pump and gas boiler. Electrical heating was ruled out in this case because it is difficult to separate the share of heating and other electricity consumption of the property. In addition, in some places the tenants pay the whole heating bill of direct electrical heating.

The mean SEC of TA's buildings for heating energy is 128 kWh/m^2 while the median is 129 kWh/m^2. The zero energy building built for Tampere house fair in 2012 had the lowest SEC of 38 kWh/m^2. The buildings with highest values were, in general, older buildings built with previous building code that did not have so tight requirements for energy efficiency. A suitable target for energy efficiency improvement actions would be to focus on the long tail of buildings with high energy consumption. However, looking only at the buildings with high SEC does not reveal the financial saving potential of energy efficiency improvements. Thus, the total energy consumption and cost need to be considered as well.

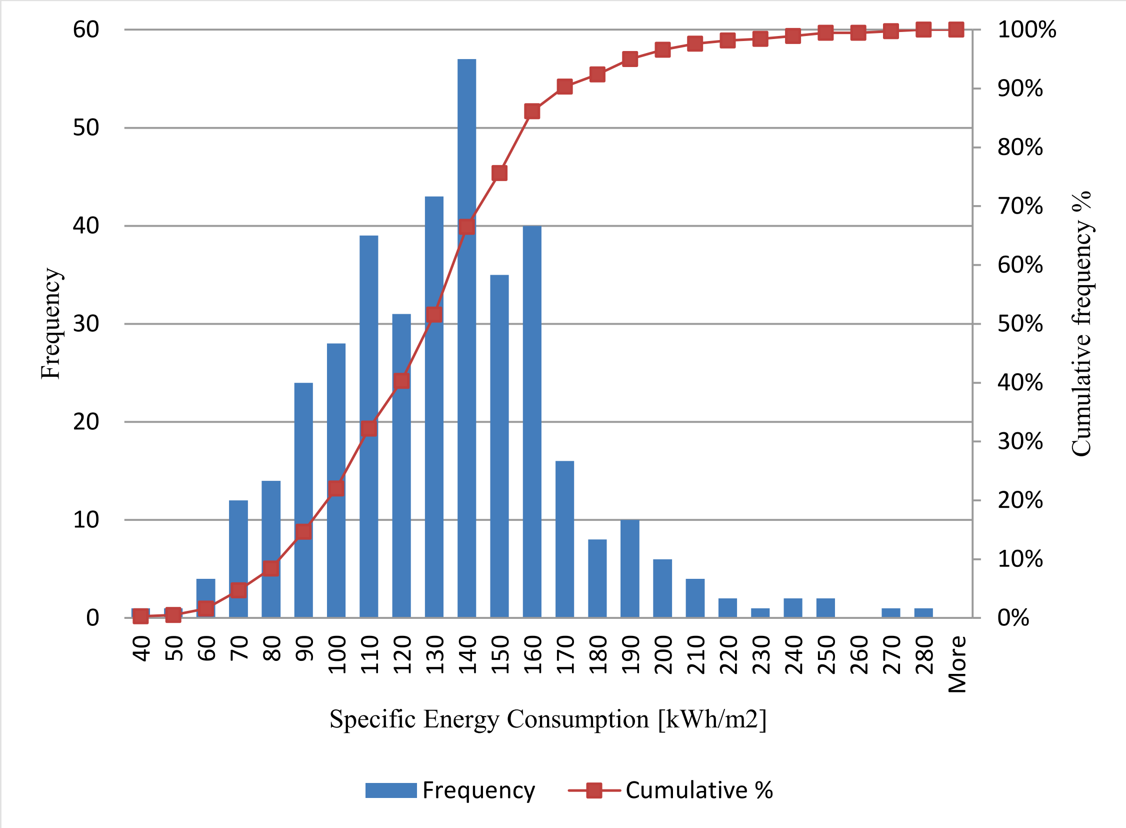

Figure 28. Histogram of the SEC of the building stock (only heating)

Although heating energy SEC is a suitable indicator for comparing the performance of different buildings, it does not typically tell the whole truth. Currently, modern HVAC systems tend to use more electricity compared to earlier ones. As a result, it is commonly needed to consider the electricity consumption as well. This can be done simply by calculating the heating and electrical energy consumption together to form a new SEC. The mean of the new SEC calculated this way is 142 kWh/m^2 and the median is 141 kWh/m^2. The values ranged between 54 and 276 kWh/m^2 and the histogram can be seen in Figure 29.

When the specific energy consumption of district heated buildings was plotted according to the construction year of the building a declining trend was discovered (Figure 30). Especially subsequent to the year 2003 the energy consumption of buildings has started to decrease even more rapidly. This can be mostly explained with the new building code that required installation of heat recovery system to exhaust air with at least 30 % efficiency. In 2010, this requirement was increased to 45 % which improved the efficiency of buildings even further.

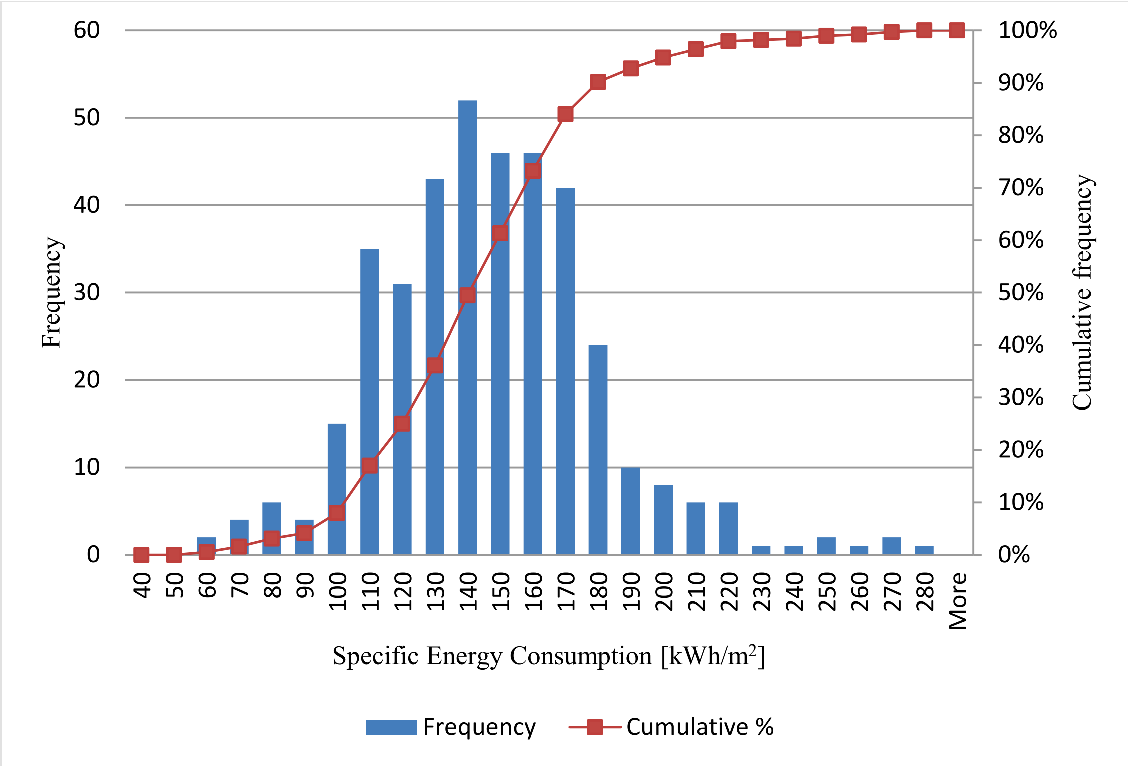

Figure 29. Histogram of the SEC of the building stock (heating + electricity)

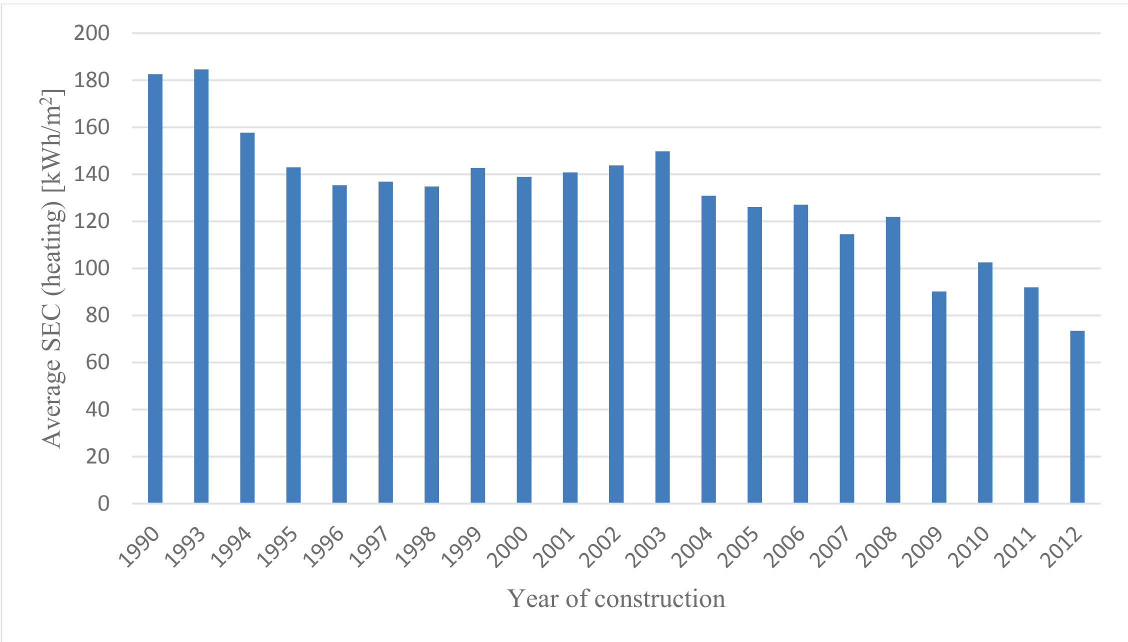

Figure 30. SEC (heating) according to the construction year of a building

The SEC with heating and electrical energy can be also plotted according to the construction year. The situation does not change much and the declining trend can still be seen especially subsequent to the year 2003. It is reassuring that despite the more advanced heat exchangers and HVAC systems which use more electricity the total energy consumption is still declining. The Figure 31 has still one limitation because it does not reveal the variation of SEC between buildings that are built during same year. A scatter plot (Figure 32) does not have this limitation. It reveals that buildings with same age can be in very variable condition and have significantly different consumptions.

Figure 31. SEC (heating + electricity) according to the construction year of a building

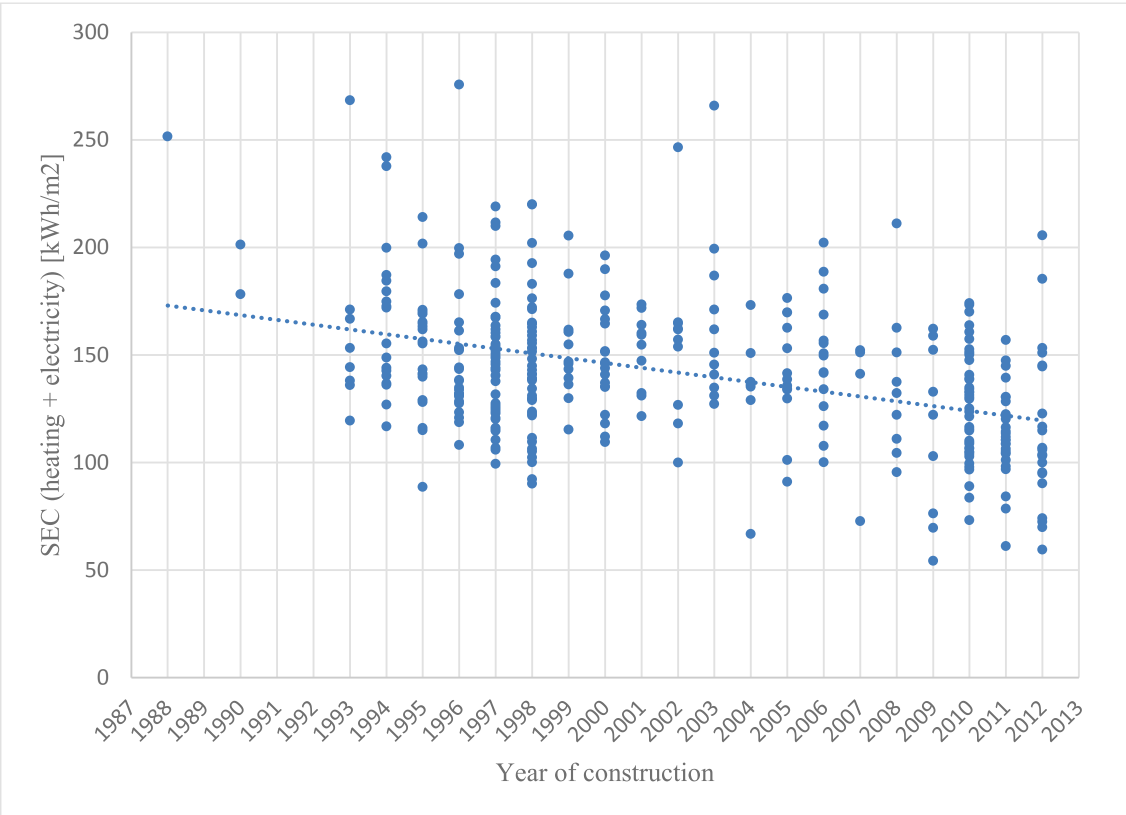

Figure 32. Differences of SEC in buildings

Water consumption costs are the second largest subsequent to heating energy costs for TA. Therefore, it is important to take the water consumption into account when analyzing the energy consumption of a building. In addition, the heating energy consumption is related to the water consumption because hot water needs to be heated with the same system that is used to heat the building. The correlation of water and heating energy consumption is decent (Figure 33), which means that if water consumption is reduced also heating energy consumption is reduced. The difficulty in reducing water consumption is that it is mostly due to tenant behavior which can be difficult to change. However, TA has gotten rewarding results by changing toilet seats and taps to water saving ones.

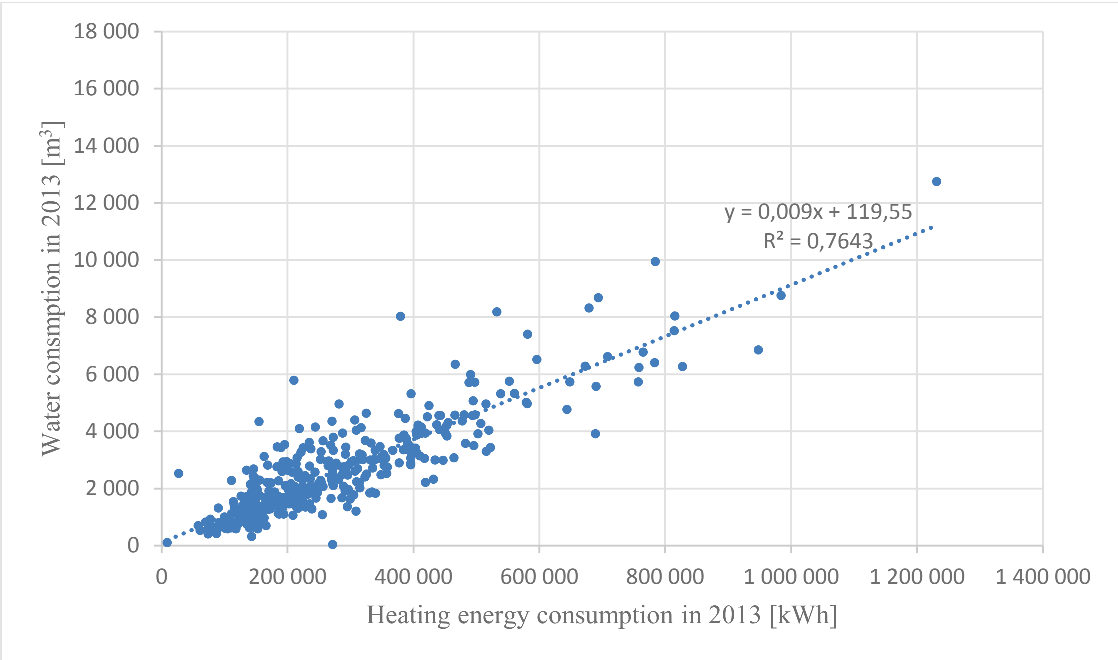

Figure 33. Correlation of cold water and heating energy consumption

Another declining trend was found when the combined costs of heating, electricity and water per square meter were plotted in relation to the year of construction (Figure 34). However, the variation is still very high within buildings built during the same year. The highest values were usually in buildings with small floor space. It is encouraging and important that despite the increase of complex HVAC systems in newer buildings (which increase electricity usage and costs) the trend is still declining. If the unit costs were increasing at the same time with built area, it would result in even more rapid increase in the total costs. In the long term this could be detrimental to the company.

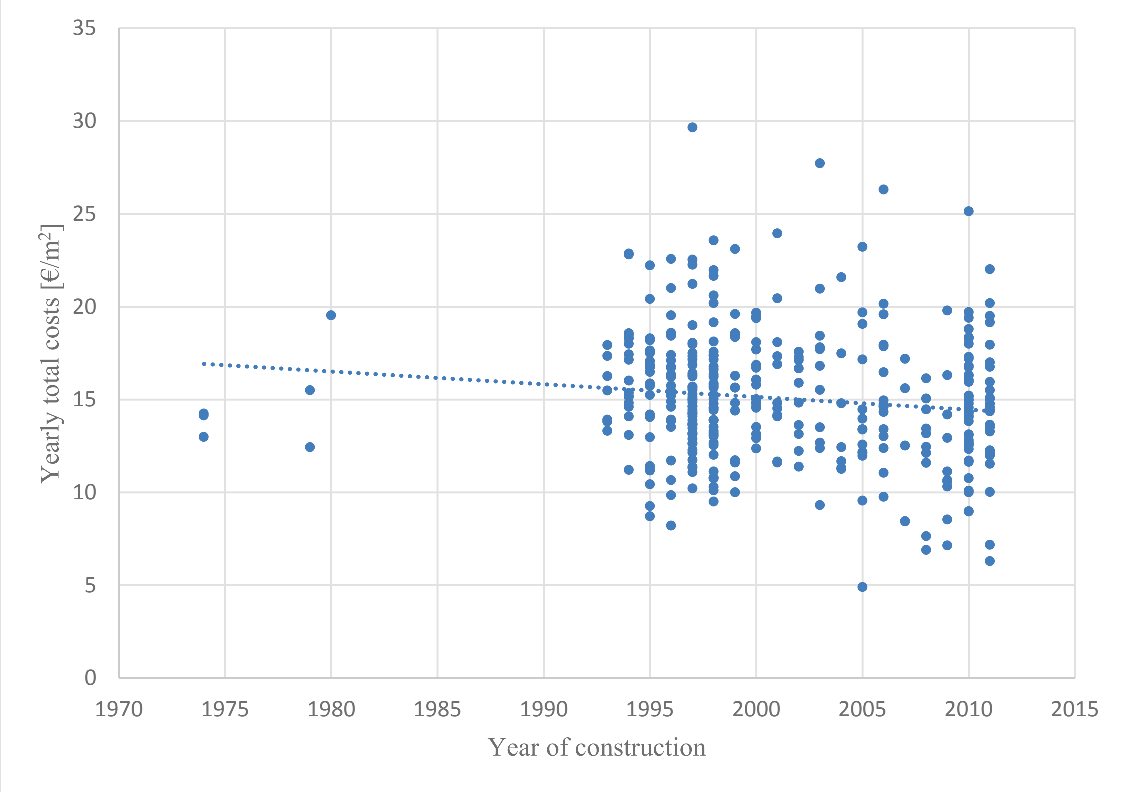

Figure 34. Monthly total cost for heating, electricity and water

4.2 Routine monitoring and analyses

Routine monitoring cycle is the continuous process where energy and water consumption data are collected and analyzed. Based on these analyses it is decided whether the performance of a building is acceptable or does it need further attention. Many useful analysis methods were already introduced in the previous section when present state of the building stock was analyzed. In this section, a few more of the analysis methods are introduced that have been found most interesting and useful when analyzing a large building stock.

4.2.1 Consumption data normalization

Normalization means that weather and temperature dependent variation is removed from the consumption data by using heating degree days. In other words, the normalization shows how the buildings would perform if they all had same temperature and weather conditions.

I think that the normalization is a suitable process for comparing the consumption of buildings between different years and different locations because the weather and temperatures varies considerably around Finland. Basically, the normalization decreases the consumption of buildings located in cold areas and increases the consumption of buildings located in warmer areas, especially if all buildings are normalized to the same national reference city. The method is appropriate especially when analyzing the consumption of buildings prior and subsequent to retrofitting because years will differ from each other and that may cause confusion in the energy saving calculations.

On the other hand, from the cost reduction point of view, the investments must be made in the places where best financial possibilities exist for energy savings. It is important to analyze the real consumptions and not the normalized ones to find the best possibilities for reductions. If normalized figures were used in investment calculations it may lead to errors. Therefore, it is not straightforward whether normalization should be typically used.

4.2.2 Analysis methods

An interesting way to gain new insights from the building stock is to try to find so-called S-curves. If found, they reveal interesting information about the individual data points that differ from the majority. Two examples of these S-curves are presented in Figure 35 and Figure 36. The values in Figure 35 are normalized to remove the variation of heating need because of climatic differences. The most interesting part of these are the very ends of the graphs. Often they exhibit the Pareto principle or 80/20-rule. In this case it means that only a fraction of buildings are responsible of most of the costs. This can be clearly seen in the figures where the end starts to rise very steeply. These individual buildings, which are in the end of the line, should be taken under more detailed analysis, unless there is a clear reason for the higher values. It should be remembered that it might be worthwhile to look at also the lowest values in there figures because they might reveal some favorable practices that could be implemented also elsewhere.

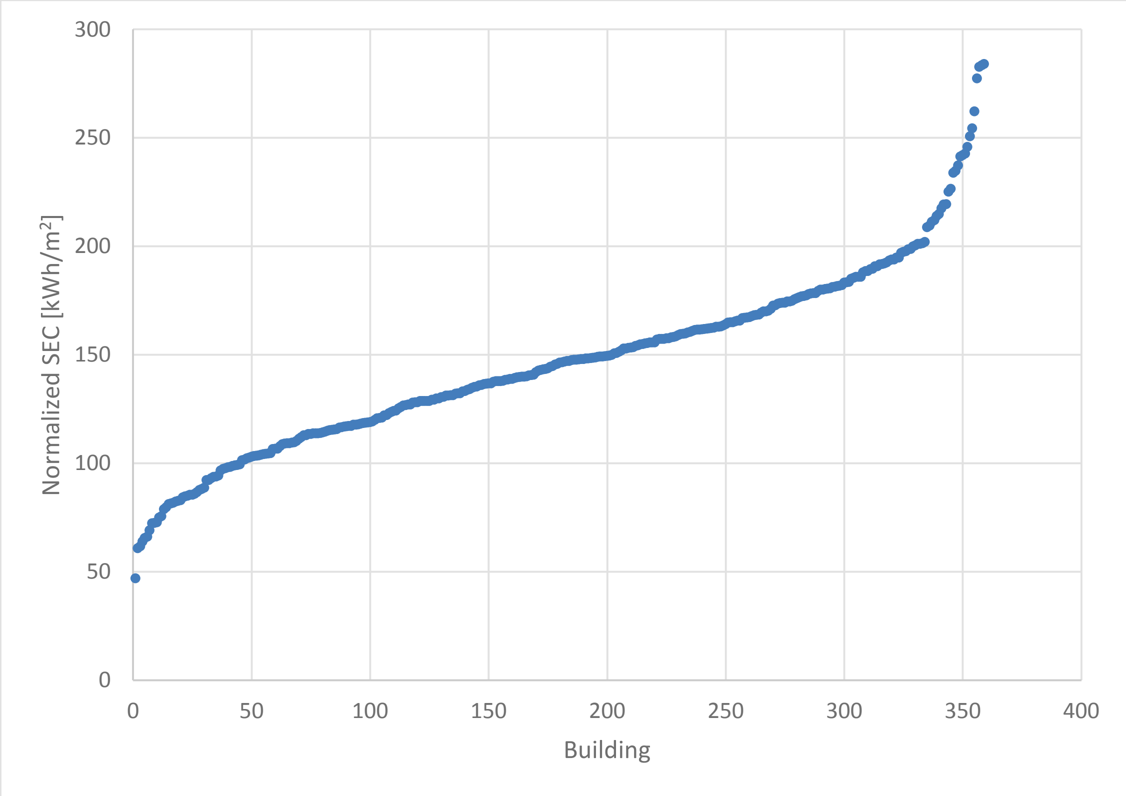

Figure 35. Normalized SEC of buildings arranged in ascending order

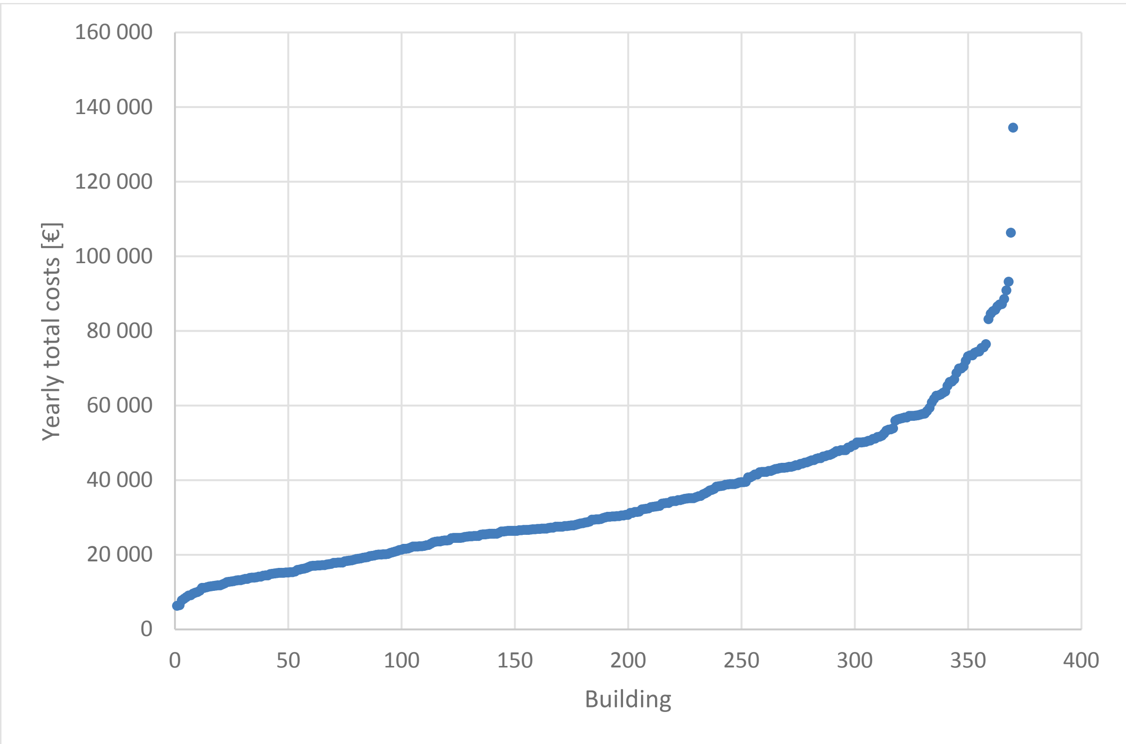

Figure 36. Yearly total costs of buildings organized in ascending order

4.2.3 Determining whether building performs according to targets

The central question of the EOM is whether a building is allowed to continue in the routine cycle or does it require special attention. Next, a new kind of energy performance indicator is proposed which will help to answer this question.

The indicator needs to be simple and unambiguous order to asses and compare buildings objectively. It should be easy to calculate and interpret and it needs to take real energy consumption, total energy costs and unit price of energy into account. The main purpose of the indicator is that it reveals the worst performing individuals from the large building stock that have largest (financial) energy saving potential. In addition, target values can be set and the indicator can reveal the buildings that are not meeting the criteria. What is more, the indicator can be used to spot the best performing individuals so that the best practices can be copied to other buildings as well. The indicator will be called as Energy Performance Indicator (EPI). In other words, the EPI can be used as a tool to identify the buildings that need special attention.

In the EOM process, the limits for the indicator as an acceptable energy performance can be given as absolute or relative. If absolute limit is set, it means that every building that reaches the limit needs to be audited. In the beginning, this approach can lead to a large amount of buildings that need auditing if the limit is set tight. Another approach is to set a relative target. For example, target can be to assess 5 % of the worst performing buildings. This may be better approach in the startup phase of the EOM process because the focus is really on the worst performing individuals.

The EPI was created simply with an Excel spreadsheet using consumption and cost data from district heating, electricity and water usage of each location (buildings located in one address). The consumption data that was used was the two year (2012 and 2013) average actual consumption of the target. Only buildings built prior to 2012 was considered in this calculation because they had at least two full years of consumption data available. In addition, the buildings that had obviously faulty consumption data was removed from the sample. In the spreadsheet, it is possible to give different weighting multipliers if, for example, it is decided that it is more important to focus on heat consumption than electricity consumption. Now, heating was given 60 % importance, electricity 20 % and water 20 %. The individual values of a target is compared to the maximum value of the same type in the building stock to form a relative comparison. Finally, the different factors for district heating, electricity and water consumption are combined and scaled so that a single value is formed. The final result is an indicator that shows a value between 0 and 100. Low values indicates poor performance and high values excellent performance. This kind of indicator is very easy to interpret even without technical background and it is also easy to visualize if needed. Another positive aspect is that once the calculation is set up in the beginning, it is performed automatically for the rest of the building stock. A downside is that at the moment the source information on energy consumption and cost need to be manually combined in a spreadsheet.

One simple way to visualize the EPI data is to make an automatic conditional formatting in Excel and make a color scale of the EPI figures. The lowest numbers are colored red and highest numbers colored green. This is a very easy way for everyone to understand whether the building performs well or poorly. Below, in Table 3, twenty-five or five percent of the worst performing buildings are presented with the illustrative color scale. These buildings are also at the same time the first buildings that should be given special attention. Table 4, on the other hand, presents ten of the best performing buildings amongst the building stock. It is needed to remember that the EPI benchmarks the buildings within the building stock against each other. It means that the buildings with the highest scores could be still improved further even though they are performing better than most of the other buildings in the building stock.

Table 3. Twenty-five worst performing buildings

Building ID	Location	Year of construction	Final EPI
3254	Vantaa	1974	17,17
4240	Espoo	1994	35,44
4122	Helsinki	1999	37,31
4220	Espoo	1993	37,54
2107	Helsinki	1998	38,03
4382	Helsinki	2011	40,23
3758	Pirkkala	1974	40,82
4152	Turku	2000	42,68
4261	Vantaa	1995	43,11
4225	Espoo	1993	43,19
5502	Oulu	1999	43,62
4224	Espoo	1997	44,72
4180	Kangasala	2001	45,31
4124	Kirkkonummi	2001	45,92
3759	Hämeenlinna	1974	46,14
4229	Espoo	1997	46,18
4215	Espoo	1993	46,23
4508	Vantaa	2000	46,37
4143	Espoo	2000	46,44
5602	Kempele	2008	48,90
4518	Vantaa	1994	50,16
4328	Espoo	2010	50,21
1220	Oulu	1996	50,46
4227	Espoo	1997	50,55
4284	Oulu	1998	51,19

Table 4. Ten best performing buildings

Building ID	**Location**	**Year of construction**	**Final EPI**
2129	Vantaa	1996	99,05
2221	Helsinki	1927	98,50
3263	Espoo	2004	96,53
2127	Vantaa	1996	96,51
3234	Espoo	2004	95,91
4127	Vantaa	1998	94,38
2128	Vantaa	1995	94,29
4163	Oulu	2005	94,29
4256	Salo	1996	94,07
1225	Porvoo	1995	94,04

Another relatively straightforward alternative is to make a scatter plot if the total consumption of a building and the SEC as have been done in Figure 37. This method quickly reveals the buildings that consume considerably in absolute and relative measures. In the figure, the worst performing buildings are the ones with large total consumption in combination with large SEC and they can be found from the upper right corner. The limitation of this method is that it does not take into account the total cost of energy in the same figure, although it can be plotted separately. Also, it is not simple to draw the lines for acceptable consumption limits because every spot is a tradeoff between total consumption and SEC. Thus, this method requires more expertise from the person doing the interpretation. In addition, the selection of the buildings needing special attention need to be done manually with this scatter plot. However, this kind of analysis gives more insight in selecting the buildings that does not have acceptable consumption. In addition, it should be verified that this and the EPI give somewhat similar results. Similar results with both methods will indicate a higher reliability. The two different methods of selecting buildings for the special attention cycle are compared in Table 5.

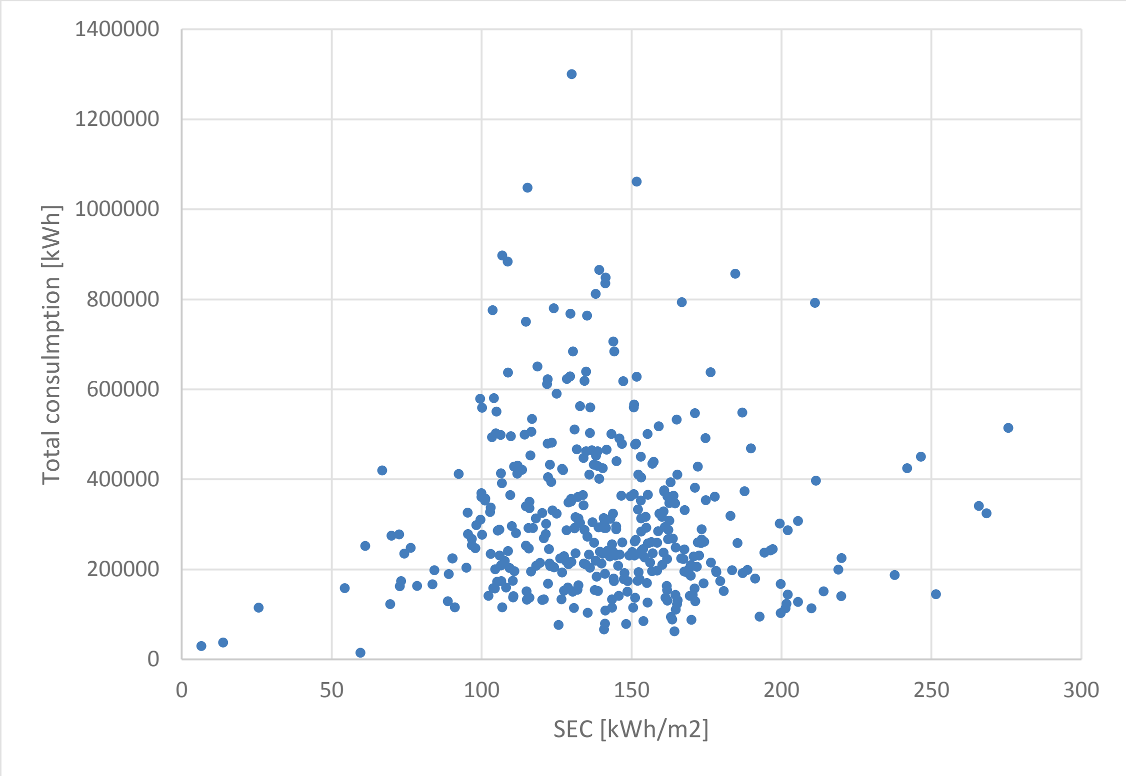

Figure 37. A scatter plot of total consumption and SEC

Table 5. Comparison of EPI and scatter plot methods

	EPI	Scatter plot
Easy to visualize	x	x
Easy to interpret even without expertise	x	
Unambiguous way to select the worst performing buildings	x	
Gives deeper insights on the performance of the building		x

4.3 Special attention cycle for poor performing buildings

Subsequent to the identification of the few single buildings with poor energy performance from the building stock it is time to analyze them further. Analyzing only a few or single buildings allows using different methods compared to analyzing a large set of buildings. This section focuses on these analyses in the special attention cycle meant for the buildings that do not perform well enough.

4.3.1 In-depth analysis

When a building does not perform well enough it will enter the special attention cycle and thorough analyses of the performance are started. A problem still exists if there is many buildings needing special attention. For example, if 5 % of TA's worst performing buildings are selected it is still 25 buildings needing special attention. This problem can be solved by reducing the selection to only one of two percent or prioritizing the selected twenty-five buildings.

One method to analyze the performance is to make a linear regression analysis of heating degree days and heating energy consumption of a single building. This shows quickly the changes in the heating need of the building when the outside temperature changes. It is also possible to compare one or a few buildings or the situations prior and subsequent to an energy performance improvement measure. The downside of the linear regression analysis is that is very time consuming to plot the charts for every building in the building stock. Therefore, it is more efficient to perform the analyses only for a chosen few buildings that require special attention. A suitable way would be to compare the worst performers to the best performing buildings to see the differences. On the other hand, a numerical analysis of the intercept, gradient and R^2 of linear correlation analysis is easy to perform on a spreadsheet even for larger amount of buildings. This can be used to prioritize the buildings in the special attention cycle. From the spreadsheet it is quick to see which buildings have high enough R^2 and the largest base loads or gradients. After that, it is possible to focus only on chosen individuals for further analyses. This will allow focusing effort first only to the buildings that are in the worst condition.

Because monthly energy consumption figures have been available for most of TA's buildings since 2012 and the HDD figures are freely available for cities around Finland, it is relatively easy to create the linear regression analysis. Below, in the Figure 38, a regression analysis was performed for four different buildings. The differences between the buildings can be clearly seen in the gradients and intercepts of the regression lines. However, part of the reason for differences are the different sizes and locations of the buildings. The equations reveal that the base loads for these buildings vary between 4.6 and 32.5 MWh per month. What is more, in two of the buildings the gradient is much steeper which means that heating energy consumption rises significantly more rapidly when outside temperature falls and HDD increases. This implies that these two buildings do not perform as well as the other two. The differing sizes of the buildings can be taken into account by using specific heating energy consumption (SEC) instead of total heating energy consumption. SEC reveals the real differences between the buildings that could not be seen earlier. This situation can be seen in the Figure 39. Now, the base load varies between 5.6 and 6.9 kWh/m^2 in all of the four buildings which means that they have relatively similar base load in relation to the heated floor space. However, some variation in the gradients can still be seen which is due to different building properties.

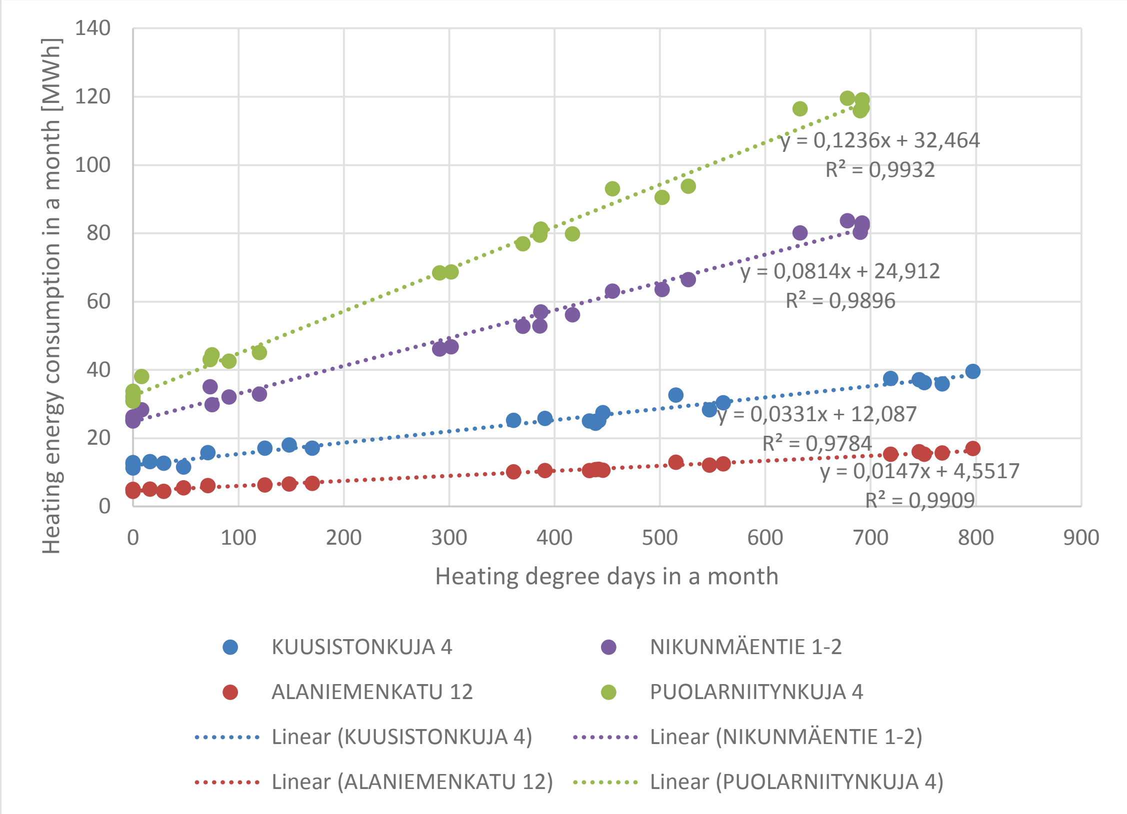

Figure 38. Linear regression of HDD and heating energy consumption

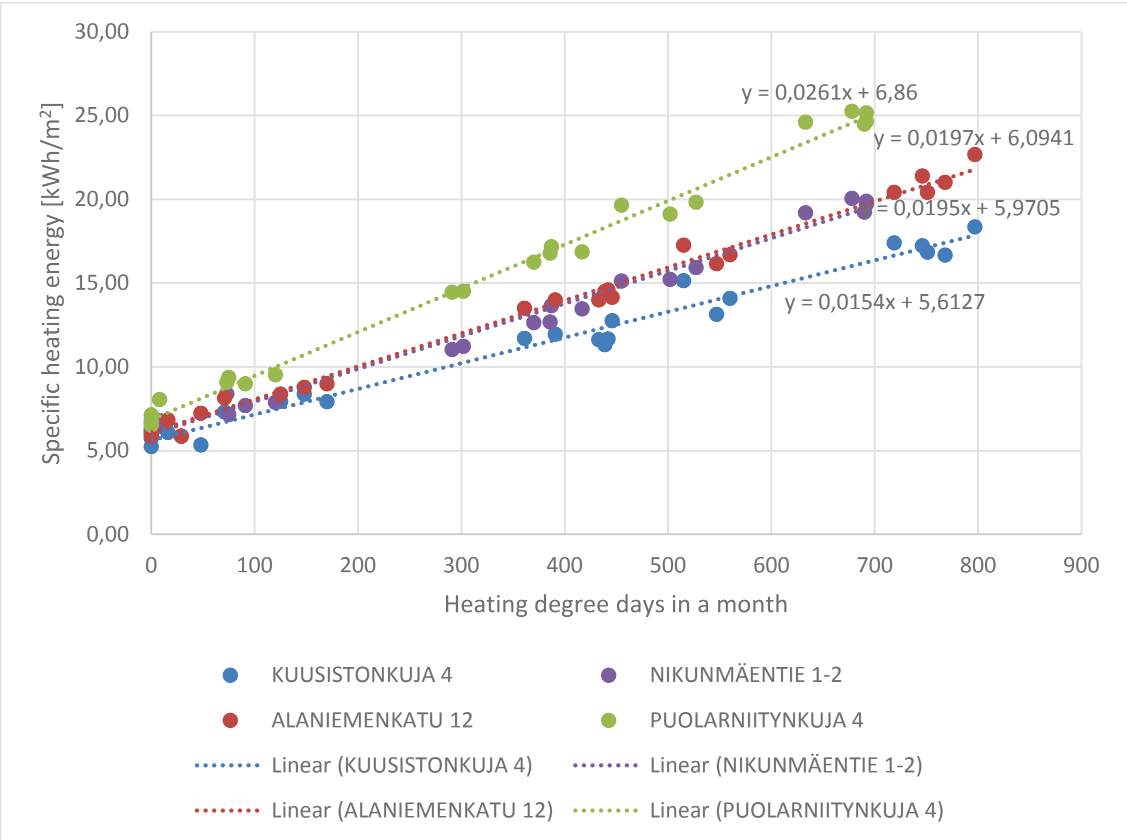

Figure 39. Linear regression of HDD and SEC

Table 6 presents an example of the numerical analysis of linear regression. It can be seen that the gradients vary considerably between buildings indicating that the consumption of some increases much faster that in others. Intercept, on the other hand, tells the base load of the building in kWh/m^2 per month. Also, the base load varies notably between some buildings. R^2 tells about the quality of the correlation. For example, buildings 4106 and 4108 has an unacceptable low R^2 which means that they should be removed from the analysis. This kind of numerical analysis is a good tool to prioritize the buildings if there is many buildings needing special attention. It is most important to focus to the buildings with the highest gradient and intercept.

Table 6. An example of numerical analysis of linear regression

Building ID	Gradient	Intercept	R^2
4101	0,033	12,087	0,98
4102	0,034	6,397	0,98
4103	0,033	10,865	0,99
4104	0,056	17,325	0,98
4105	0,033	5,138	0,96
4106	0,031	6,737	0,54
4107	0,036	6,082	0,95
4108	0,034	5,546	0,63
4111	0,048	13,982	0,93
4113	0,097	11,763	0,98
4114	0,026	7,630	0,94
4115	0,027	5,215	0,94
4117	0,061	18,818	0,98
4118	0,070	15,409	0,97
4120	0,091	8,446	0,90
4121	0,045	9,964	0,94
4122	0,145	40,642	0,85
4123	0,033	7,447	0,94
4124	0,097	22,170	0,95

Qualitative analysis methods are also very practical in the special attention phase where the amount of buildings is considerably lower. For example, it is possible to compile a checklist that has all essential variables that affect the energy performance of a building. With the help of the checklist, it is quick and easy to qualitatively analyze the poor performing building to see whether all fundamental building systems work as they should. In addition, by using the checklist, one can be sure that all buildings are analyzed exactly the same way and nothing important will be forgotten.

4.3.2 Towards retrofit implementation

Subsequent to detailed analyses it is time to choose a few buildings as targets for energy assessments. These assessments can be performed by an in-house specialist or another alternative is to outsource them. In the long term, it is essential to have the capabilities to perform assessments in house because it is a continuous process to perform them. The purpose of these assessments is to provide more information concerning the condition of different systems and elements of the building. Based on this information a set of possible retrofits will be chosen for feasibility and profitability analyses.

With limited investments, simple payback time analysis will be usually enough to evaluate the rationality of the investment. Larger investments, on the other hand, require much more thorough investment profitability calculations. In the end, it is up to the management of the company to decide the guidelines which are followed when evaluating different investments.

The last steps in the special attention cycle are to implement the energy conservation measures and to verify their performance by monitoring the building also afterwards. Finally, the cycle starts again and new ECMs are implemented to other buildings.

4.4 Summarizing and discussing the EOM process

The EOM process solves the issue of focusing work effort in analyzing a building stock which was not covered in the academic literature. The process divides the buildings in the building stock into two categories based on their energy performance. Buildings with good performance are only gone through a quick and simple analysis process and buildings with poor performance will go more thorough analysis. This will reduce the effort needed by optimizing analysis work.

A new tool called Energy Performance Index (EPI) was developed to simplify the step of selecting the buildings that need special attention within the EOM process. EPI benchmarks buildings against each other within the portfolio by using heating energy, electricity and water consumption and cost data. A single figure is formed and it will be visualized as well as used to rank the buildings according to their energy performance. The visualization will also make the EPI easy and fast to understand. The scatter plot method can be used to verify the gotten results from the EPI ranking. It will be slightly harder to interpret but the scatter plot will give more insights about the dimensions of the performance. Depending on the selection, the EPI can identify a few or multiple buildings that need special attention. If many buildings are identified, linear regression method can be used to prioritize the buildings in the special attention cycle. It was also discovered that the intercepts and gradients in the linear regression analysis can reveal that the energy consumption of the buildings may behave very differently when the outside temperature decreases.

By following the EOM process it is possible to create a structure around the energy performance investments. As discussed before, Eneron offers a service that is similar to the EOM. Also, some other suppliers may have similar offerings. However, TA (or any company) needs to be careful if they wish to buy the EOM as a service or outsource the whole process of improving energy performance. It may lead to a situation in which the company becomes dependent on the supplier and cannot change to a different supplier without a substantial cost. However, if the company itself manages the essential parts of the EOM it is possible to outsource parts of the process without a risk of a lock-in situation. What is more, some suppliers may even be able to provide certain parts of the process more efficiently than the company itself could. In addition, if better solutions arise, it is possible to change the supplier to get more value from some other.

5 DISCUSSION

This chapter discusses the results of the thesis and how they relate to literature. In addition, recommendations are given based on the findings made in chapters three and four. The last sections of this chapter analyze the limitations of this study and give proposals for further research topics

5.1 Reflecting the results

This thesis has a strong background in the academic literature. Roughly a hundred articles or studies were explored for useful insights and knowledge. In addition, dozens of non-academic publications and reports were read to gain more insights from the field. Thus, it can be said that a strong theoretical background was formed for this thesis.

Literature in the field of energy efficiency in buildings proved to be quite practical. However, majority of the articles or studies covered a limited area of the field and was not necessarily usable for a company as such. This thesis combined the most practical aspects of the literature, and made the findings easily usable for a single company that seeks to improve the energy efficiency of its buildings. The methods that were suggested had been always used in a similar context in an academic study. The only thing that did not have direct reference was the Energy Performance Indicator that was developed to spot inefficient buildings. However, the EPI was essentially quite simple and straightforward so the lack of academic reference was not a problem. Altogether, the thesis managed to translate academic findings into easily implementable recommendations that are practical in a business context.

The objective of this thesis was to create a comprehensive and systematic process to manage energy performance of a large building stock. To create a better structure for the research, two research questions were formed: (1) How the energy performance of a building stock can be managed? and (2) How the energy performance data can be utilized in a useful way? The objective was fulfilled well with the developed Energy Operations Management process. Also, both of the research questions were answered by introducing multiple analysis methods to process and utilize energy consumption data. Therefore, it can be argued that this thesis succeeded in fulfilling the requirements given to it as well as creating new knowledge from the field of energy efficiency in buildings.

5.2 Recommendations

My recommendations for TA’s next steps can be divided into eight proposals: (1) creating an energy policy, (2) setting performance targets, (3) developing a database, (4) starting the EOM process, (5) productizing investments, (6) benchmarking, (7) design energy efficient buildings, and (8) starting an education campaign. Next, these proposals are discussed further.

The first step for TA is to form a clear written energy policy. The policy needs to show the quantified targets for energy efficiency improvements and the deadline before which these targets need to be achieved. All relevant employees should be involved in the process of creating the policy to make it widely accepted among them.

Secondly, after completing and approving the policy, the targets can be taken into the analyses and into the EOM process. Now, the analyses in EOM reveal the poor performing buildings from the stock and concrete calculations can be made for efficiency improvements. Also, the energy assessments can be started from the buildings that require it the most. By starting the EOM it is ensured that the energy efficiency improvements will form a systematic process instead of a set of unrelated actions. When the process has been running for a period of time, it is important to adjust the energy policy and the targets to maintain a slight pressure in order to continue the constant development.

Thirdly, a tool or database needs to be developed that will collect and combine all relevant information and data that is related to the energy efficiency of buildings. This means information, such as consumption data, basic information on building characteristics, a record of implemented ECMs, building specific maintenance plan, and energy performance targets. Without a single database it is difficult to get a deeper understanding on what is happening in the building stock. In addition, it will be laborious to manage the EOM process if the data is in disorder. On the other hand, this kind of new database that combines all relevant data for a company is nearly like an enterprise resource planning tool that is not easy nor cheap to start using. Thus, it must be clearly considered what features this kind of software or database should include.

The fourth step is to start using the EOM process. At first, the process may not be very well organized or automated. The calculations may be manual and also selecting the buildings for the special attention cycle needs to be done manually. Gradually, as the process becomes more familiar, it may be worth doing some investments to automate the process so that the manual work can be reduced. After some time, the process will hopefully become an integral part of managing the energy performance of the building stock.

Fifthly, an important issue is that the energy efficiency investments are optimized to maximize the savings with a given sum of money. However, optimization does not create more value when a certain point has been bypassed. Thus, it is better first to get it roughly correct and then make improvements next time. One option is to productize the energy conservation measures that have been discovered profitable and start to implement the same measures to many buildings. This way the planning and analysis phase can be done only a few times but the benefits are gotten from multiple places. Productization of the measures may require dividing the building stock into categories of similar buildings (building typology). Later, same energy conservation measures can be implemented to the whole category.

Furthermore, the field of energy efficiency is evolving at a huge pace at the moment. New technologies arises all the time, and new applications for existing technologies are found constantly. Therefore, it is important to search new technologies or processes for energy efficiency that may become cost effective and profitable for the company. Also, it might be worth piloting some technologies that are not so obvious on a limited scale at times. This might lead to unexpected positive discoveries. In addition to new technologies, benchmarking other similar companies is an advantageous plan. It might be possible to learn beneficial practices from competitors that have not been thought earlier. It also allows the skipping of the trial and error part of trying new energy efficiency methods which can save a considerable amounts of time and money. In addition, some of the work could be outsourced to third parties that are able to focus on a specific task and provide solutions more effectively compared to the option that it would be done in house.

When it comes to the designing new apartment buildings, energy efficiency aspects should get a larger role already in the design phase. When the building is still on the drawing table, possibilities for energy efficiency improvements are largest and they are cheapest to implement. Subsequent to the completion of the building, it will be much more expensive to start to change and improve building systems and characteristics.

Finally, it might be also worthwhile to start an education campaign for the current tenants regarding energy efficiency. This would increase the energy awareness of the tenants and might lead to energy savings. One option is to provide some of the buildings with information screens containing visualized data about the recent energy consumption.

5.3 Limitations of the study

The EOM is a new way of operating a significant part of a property management company. Therefore, it cannot be tested reliably only in theory because it is really a hands-on process. Starting the EOM in a company requires effort and time to see how it starts to work in practice with actual consumption data within a longer period of time, and that cannot be fully done within the scope of this thesis. Thus, a risk exists that parts of the EOM process are not practical and they may cause difficulties in the execution phase. Starting EOM is therefore an iterative process where the advantages and disadvantages are learnt little by little and adjustments to the process are made regularly.

Secondly, the uncertainty of the reliability of the source data caused some problems in the calculation phase in the beginning. Even though majority of the data was verified and corrected, some of it still may have errors in it. Therefore, outliers in the data and in the analyses must be treated with caution. In some analyses, part of the buildings needed to be ruled out of the sample because the data was missing or obviously faulty.

5.4 Topics for further research

Simple and practical methods are needed to optimize energy efficiency investments. At the moment, many methods to optimize investments that are presented in academic articles are too complex to be used in daily situations. I argue that much simpler methods would be more valuable for most companies in their operations.

As a result of this study, the EOM process, provides an interesting stepping stone for new research to develop the process even further. As noted earlier, much of research focuses on quite narrow fields and this kind of wider approach has not been well represented. The EOM could be tested in multiple different contexts to determine more about its strengths and weaknesses.

Additionally, it would be interesting to read research concerning the optimal way of storing and managing data and information in this kind of situation. Most likely it would be some kind of online database. However, it would be interesting to learn about different ways to execute it.

6 REFERENCES

ASHRAE, 2010. *Performance Measurement Protocols for Commercial Buildings.* American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.

BALLARINI, I., CORGNATI, S.P. and CORRADO, V., 2014. Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project. *Energy Policy,* **68**(0), pp. 273-284.

BIZEE, 2014, 2014-last update, Linear Regression Analysis of Consumption Data [Homepage of BizEE Software Limited], [Online]. Available: http://www.degreedays.net/regression-analysis [06/09, 2014].

BON, R., 1994. Ten principles of corporate real estate management. *Facilities,* **12**(5), pp. 9.

CAPEHART, B., TURNER, W. and KENNEDY, W., 2006. *Guide to energy management.* The Fairmont Press, Inc.

CORGNATI, S.P., CORRADO, V. and FILIPPI, M., 2008. A method for heating consumption assessment in existing buildings: A field survey concerning 120 Italian schools. *Energy and Buildings,* **40**(5), pp. 801-809.

CORGNATI, S.P., FABRIZIO, E., FILIPPI, M. and MONETTI, V., 2013. Reference buildings for cost optimal analysis: Method of definition and application. *Applied Energy,* **102**(0), pp. 983-993.

DALL'O', G., GALANTE, A. and PASETTI, G., 2012. A methodology for evaluating the potential energy savings of retrofitting residential building stocks. *Sustainable Cities and Society,* **4**(0), pp. 12-21.

DALL'O', G., GALANTE, A. and TORRI, M., 2012. A methodology for the energy performance classification of residential building stock on an urban scale. *Energy and Buildings,* **48**(0), pp. 211-219.

DASCALAKI, E.G., DROUTSA, K.G., BALARAS, C.A. and KONTOYIANNIDIS, S., 2011. Building typologies as a tool for assessing the energy performance of residential buildings – A case study for the Hellenic building stock. *Energy and Buildings,* **43**(12), pp. 3400-3409.

ECONOMIDOU, M., 2011. *Europe's buildings under the microscope A country-by-country review of the energy performance of buildings.* Buildings Performance Institute Europe (BPIE).

EU, 2010. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast) . *Official Journal of the European Union,* .

EVO, 2012. *International Performance Measurement and Verification Protocol - Concepts and Options for Determining Energy and Water Savings Volume 1.* EVO 10000 – 1:2012. EVO Efficiency Valuation Organization.

FMI, 2014-last update, Heating Degree Days [Homepage of Finnish Meteorological Institute], [Online]. Available: http://ilmatieteenlaitos.fi/lammitystarveluvut [05/20, 2014].

FORSSTRÖM, J., 2011. Measuring energy efficiency: Indicators and potentials in buildings, communities and energy systems. *VTT Tiedotteita - Valtion Teknillinen Tutkimuskeskus, 2011, Issue 2581, pp.1-118,* (2581), pp. 1-Valtion.

FRACASTORO, G.V., 2011. A methodology for assessing the energy performance of large scale building stocks and possible applications. *Energy and Buildings, April 2011, Vol.43(4), pp.844-852,* **43**(4), pp. 844-852.

GOLABI, K., KULKARNI, R.B. and WAY, G.B., 1982. A Statewide Pavement Management System. *Interfaces,* **12**(6), pp. 5-21.

IHASALO, H., 2012. *Transforming building automation data into building performance metrics design, implementation and evaluation of use of a performance monitoring and management system.* Espoo: Aalto University, School of Electrical Engineering, Department of Automation and Systems Technology.

ISO, 2011-last update, ISO 50001:2011(en) Energy management systems — Requirements with guidance for use [Homepage of International Organization for Standardization], [Online]. Available: https://www.iso.org/obp/ui/#iso:std:iso:50001:ed-1:v1:en [06/11, 2014].

JUAN, Y., GAO, P. and WANG, J., 2010. A hybrid decision support system for sustainable office building renovation and energy performance improvement. *Energy and Buildings,* **42**(3), pp. 290-297.

LEWIS, A., 2011. Linking energy and maintenance management for sustainability through three American case studies. *Facilities,* **29**(5), pp. 243-254.

LIU, F., 2011. Statistical modeling for anomaly detection, forecasting and root cause analysis of energy consumption for a portfolio of buildings. *Proceedings of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, 2011, pp.2530-2537,* , pp. 2530-2537.

MAATTANEN, E., 2014. Remote energy management benefits in retail building portfolios. *Journal of Facilities Management,* **12**(1), pp. 56-71.

MARTINAITIS, V., 2004. Criterion to evaluate the "twofold benefit" of the renovation of buildings and their elements. *Energy And Buildings, 2004, Vol.36(1), pp.3-8,* **36**(1), pp. 3-8.

MOTIVA, 2014-last update, Equations: Heating energy consumption [Homepage of Motiva], [Online]. Available: http://www.motiva.fi/julkinen_sektori/energiankayton_tehostaminen/kiinteistojen_energianhallinta/kulutuksen_normitus/laskukaavat_lammitysenergiankulutus [08/12, 2014].

NOUSIAINEN, M., 2006. *Energianhallintapalveluiden kehittäminen kiinteistöpalvelualalla.* Espoo: Teknillinen korkeakoulu.

POEL, B., VAN CRUCHTEN, G. and BALARAS, C.A., 2007. Energy performance assessment of existing dwellings. *Energy and Buildings,* **39**(4), pp. 393-403.

RAMESH, T., 2010. Life cycle energy analysis of buildings: An overview. *Energy and Buildings,* **42**(10), pp. 1592-1600.

RIL, 2009. *Matalaenergiarakentaminen : asuinrakennukset.* Helsinki: RIL / Suomen rakennusinsinöörien liitto.

SARTORI, I. and HESTNES, A.G., 2007. Energy use in the life cycle of conventional and low-energy buildings: A review article. *Energy and Buildings,* **39**(3), pp. 249-257.

TABULA, 2014-last update, National Building Typologies. Available: http://episcope.eu/index.php?id=182 [06/26, 2014].

THE COALITION FOR ENERGY SAVINGS, 2014-last update, Energy audits [Homepage of The Coalition for Energy Savings], [Online]. Available: http://eedguidebook.energycoalition.eu/energy-audits.html [06/05, 2014].

THEODORIDOU, I., PAPADOPOULOS, A.M. and HEGGER, M., 2011. Statistical analysis of the Greek residential building stock. *Energy and Buildings,* **43**(9), pp. 2422-2428.

TOMMERUP, H. and SVENDSEN, S., 2006. Energy savings in Danish residential building stock. *Energy and Buildings,* **38**(6), pp. 618-626.

TRIPP, D., 2005. *Industrial Energy Management Training Course Module 4: Developing an Energy Policy.* Department of Energy: Republic of South Africa.

TUOMINEN, P., KLOBUT, K., TOLMAN, A., ADJEI, A. and DE BEST-WALDHOBER, M., 2012. Energy savings potential in buildings and overcoming market barriers in member states of the European Union. *Energy and Buildings,* **51**(0), pp. 48-55.

WBCSD, 2009. *Energy Efficiency in Buildings - Transforming the Market.* WBCSD World Business Council for Sustainable Development.

WEBSTER, J., 2002. Analyzing the past to prepare for the future: writing a literature review. *MIS Quarterly, June, 2002, Vol.26(2), p.xiii(11),* **26**(2), pp. xiii.

ZHIVOV, A., PIETILÄINEN, J., REINIKAINEN, E., SCHMIDT, F. and WOODY, A., 2009. *Energy Process Assessment Protocol.* IEA ECBCS Annex 46. International Energy Agency, Energy Conservation in Buildings and Community Systems Program.